AMERICAN UNIVERSITY OF BEIRUT

CHANGES IN GRADE 7 LEARNERS' NOS UNDERSTANDINGS AND ARGUMENTATION SKILLS AFTER ENGAGING IN REFLECTIVE DISCUSSIONS FOLLOWING ALTERNATIVE INFORMATION EVALUATION IN THE CONTEXT OF SOCIO-SCIENTIFIC CONTROVERSIAL ISSUES

by

SHAGHIG GARO CHAPARIAN

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"There is no such thing as a 'self-made' man. We are made up of thousands of others. Everyone who has ever done a kind deed for us, or spoken one word of encouragement to us, has entered into the make-up of our character and of our thoughts, as well as our success." George Burton Adams

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AN ABSTRACT OF THE THESIS OF

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Title: Changes in grade 7 learners' NOS understandings and argumentation skills after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues

This study investigated the changes in Grade 7 learners' NOS understandings and argumentation skills after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues. Specifically, this research study addressed the following questions: (1) How do grade 7 learners' NOS understandings and argumentation skills change after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues? (2) How are alternative information evaluation and argumentation skills related after engaging in reflective discussions from the perspective of the Family Resemblance Approach (FRA)? Participants in this study were sixteen seventh grade students in a K-12 coeducational Lebanese private school. This study used a qualitative research design. The participants were administered the Perspectives on Scientific Epistemology (POSE) questionnaire and an argumentation questionnaire adopted from Abd-El Khalick (2002) and Khishfe (2014), respectively, as pre- and posttests. The participants engaged in explicit instruction about information evaluation criteria (currency and accuracy) and argumentation components (claim, evidence, and counterargument). They evaluated information about alternative views regarding four controversial social issues (water fluoridation, climate change, electromagnetic wave pollution, and animal testing) using Model-Evidence Link (MEL) diagrams, and engaged in reflective discussions which were designed based on the categories of the FRA framework. FRA is a comprehensive framework that provides the opportunity for exploring NOS in contextualized and thematic instructional settings because they are dynamically interrelated (Dagher & Erduran, 2017). The FRA organizes different features and characteristics of NOS coherently to show how science functions as a system (Dagher & Erduran, 2017) and provides a broader understanding of NOS because it includes categories about NOS rather than ideas about NOS tenets only (Kaya & Erduran, 2016). The analysis of data collected from questionnaires, interviews, and discussion transcriptions showed that participants developed more informed views regarding several FRA categories such as the tentativeness of scientific knowledge, the tentativeness of personal explanations in science, the validity of information, scientific practices and knowledge construction, relationship of science with society, politics, economics, social organizations, and ethical issues in science. Also, participants improved their information evaluation scores and provided more valid justifications with evidence to support their arguments. The results showed a low correlation between alternative information evaluation skills and argumentation skills. Finally, the results showed several cases of variation in NOS views as the participants adopted a former view depending on the context of the socio-scientific issue. The results of this study may encourage practitioners to use the FRA framework to design similar instructional activities and allow students to develop a more comprehensive

view of NOS and, consequently, to acquire several aspects of a scientifically literate person. It indirectly contributes to the civic education of the students by improving their reflective argumentation, information credibility evaluation, and decision-making skills and suggests a promising approach for preparing informed and active citizens who take an active role in their communities. This research study recommends investigating the relationship between the alternative evaluation skills and NOS views in each NOS theme, to examine the possibility of developing informed NOS views through developing alternative information skills at different grade levels, and to design a vertical progression for information evaluation skills, argumentation skills, and NOS views.

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CHAPTER I

INTRODUCTION

The meaning of literacy and the nature of a literate individual have undergone a significant change over the past few decades. The literate person is not just the one who knows how to read and write. Many fields of literacy are newly defined with the changes in the needs of individuals and society. These include scientific literacy and information literacy (IL).

Similarly, with several reforms in science education, the criteria of a scientifically literate person have also evolved. Scientific literacy has turned into a multidimensional construct (National Research Council [NRC], 2012). Therefore, the scientifically literate person is not just the person who knows scientific content, but the one who can (1) discuss and make decisions about daily concerns and themes that encompass science (PISA, 2015; Sadler, 2011) and develop "functional scientific literacy" (Zeidler & Keefer, 2003) to acquire reasoning skills needed to address socio-scientific issues, (2) read and comprehend scientific reports and reflect critically on information (PISA, 2015), (3) develop an informed understanding of nature of science (NOS), and (4) value the interdependence of science, technology, environment, and society. Besides the importance of developing scientific literacy, many science educators and research studies have emphasized the importance of developing a robust understanding of scientific epistemologies. In summary, understanding NOS, especially within the context of socio-scientific issues (SSI), has become an indispensable component of scientific literacy and a significant focus of science education in recent years (Karisan & Zeidler, 2017; Sadler, Chambers & Zeidler, 2004).

NOS refers to scientific epistemology, which considers science as a way of knowing and includes the values and beliefs that are essential for scientific knowledge construction (Lederman 1992). That is the views that individuals have about the origins of knowledge, its complexity, certainty, and development (Schommer & Easter, 2007). Science education reform documents, standards, and policies (National Research Council [NRC], 1996; American Association for the Advancement of Science [AAAS]) consider NOS as one of the fundamental pillars of science education.

Although science educators agree that NOS is an essential component of the science curriculum, the conceptions about the integration of NOS objectives vary and create a debatable issue in the science education community (Stanley & Brickhouse, 2001). On the one hand, a group of science education researchers (Abd-El-Khalick, Bell & Lederman, 1998; Lederman, 2004; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003) have listed certain aspects of NOS, which are suitable for NOS instruction at schools, and gained the consensus of philosophers, historians, sociologists and science educators. For this reason, this is represented as the "consensus view." The consensus view is described as the recent commonly accepted, consensus-based aspects approach NOS (Abd-El-Khalick, 2012) such as science being tentative, empirical, subjective, and socially embedded. Lederman (2004) claims that these aspects of NOS are useful to be utilized in school contexts.

Other researchers (Irzik & Nola, 2011; Matthews' 1998; Norris & Korpan's 2000) oppose Ledermen's (2004) conceptualization of NOS and suggest other approaches as possible ways for addressing NOS in schools. Irzik and Nola (2014), following Wittgenstein's work, proposed the Family Resemblance Approach (FRA). They consider that FRA is a more comprehensive alternative to the consensus view**.** They represent NOS as a "cognitive-epistemic" and "social-institutional system." The cognitive-epistemic system includes "processes of inquiry, aims and values, methods and methodological rules, and scientific knowledge" (p. 20). The social-institutional system refers to "professional activities, scientific ethos, social certification and dissemination of scientific knowledge, and social values" (p. 20).

Erduran and Dagher (2014) re-conceptualized the FRA proposed by Irzik and Nola (2011) to make it more applicable in science education. They added three other categories: "Social organizations and interactions," "political power structures," and "financial system." The re-conceptualized categories of FRA are visually represented in the FRA wheel (see Figure 1). FRA categories provide the opportunity for exploring NOS in contextualized and thematic instructional settings because they are dynamically interrelated (Dagher & Erduran, 2017). FRA organizes different features and characteristics of NOS coherently to show how science functions as a system (Dagher & Erduran, 2017). According to Kaya and Erduran (2016), FRA provides a broader and more comprehensive understanding of NOS because it includes categories about NOS rather than ideas about NOS tenets only (Kaya & Erduran, 2016).

Considering the comprehensiveness of this new approach of addressing NOS, the proponents of FRA find the consensus view fragmentary. They criticize the consensus view in terms of not reflecting contemporary scientific activities, often misleading and confusing individuals (Hosdson & Wong, 2017), being limited in addressing NOS as an educational objective, not reflecting ways of using these aspects and understandings in different contexts, not serving as "means to socio-scientific decision making" (Yacoubian, 2015, p. 250), simplifying NOS which is misleading and confusing individuals (Hosdson & Wong, 2017), being limited in addressing NOS as an educational objective, not reflecting ways of using these aspects and understandings in different contexts, not serving as "means to socio-scientific decision making" (Yacoubian, 2015, p. 250), simplifying NOS which is complex and challenging to understand (Hodson & Wong, 2017; Yacoubian, 2015), ignoring several fields of NOS and not representing NOS holistically (Mattew, 2012). Consequently, the consensus view targets

Figure 1. Science as a social-institutional system in the Expanded Family Resemblance Approach wheel (Erduran & Dagher, 2014; based on Irzik & Nola, 2014). Reprinted by permission from Springer Customer Service Centre GmbH: Springer Nature, Reconceptualizing the Nature of Science for Science Education: Scientific Knowledge, Practices and Other Family Categories by Erduran, S., & Dagher, Z. (2014)

understandings of NOS as an educational goal that students need to comprehend without giving opportunities for applying these aspects to enhance scientific knowledge or skills. Since the consensus view is criticized for lacking the ability to create opportunities for using NOS in different contexts in parallel to developing NOS understandings, this study relies more on the FRA framework to address NOS comprehensively by incorporating NOS understandings in critical evaluation of information related to SSI issues.

The development of informed and more comprehensive understandings of NOS is essential because these understandings promote a positive behavior toward learning and improve students' achievement and participation in the classroom, particularly or in society generally. Sadler et al. (2004) claim that NOS affects the way students evaluate and interpret the supportive evidence related to socio-scientific issues. A socio-scientific issue (SSI) is described as a "context for curriculum," which creates an active atmosphere for engaging students in decision-making and argumentation concerning controversial social issues and developing their moral and ethical values (Zeidler, Sadler, Simmons & Howes, 2005). When students are engaged in SSIs, they consider the credibility of information describing the issues and the underlying moral, political, and economic dimensions of these social issues (Zeidler et al., 2005).

Science educators generally emphasize the importance of NOS understandings and developing decision-making skills associated with SSI, both of which require that students use argumentation in addressing socially relevant scientific issues (Bell & Lederman, 2003; Khishfe, 2012; Khishfe, Alshaya, BouJaoude, Mansour & Alrudiyan, 2017; Liu, Lin, & Tsai, 2011; Yacoubian, 2015; Zeidler, Walker, Ackett, & Simmons, 2002). Previous studies (Abd-El Khalick & Lederman, 2000; Akerson, Abd-El-Khalick, & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002) show that the development of NOS understandings has been more effective and prominent when addressed explicitly in reflective instructional settings. Schrijver, Tamassia, Keere, Vervaet, and Cornelissen (2016) highlight the advantages of reflection about NOS and consider that this reflection helps students to visualize abstract concepts through linking epistemic knowledge to models, examples, and experiences. Reflective discussions clarify abstract concepts as thoughts about science are guided by general or focused questions as well as promote conceptual change and NOS understanding. The effectiveness of these discussions depends on teachers' abilities to facilitate dialogue by asking appropriate questions that challenge students' ideas and lead them to reflect, hypothesize, explain, and argue about certain concepts concerning NOS. These practices not only clarify abstract concepts or improve metacognition but also help students to engage in argumentation. Developing reflective argumentation skills promotes reasoning about judgments and critical decision-making (Kuhn, Cheney & Weinstock, 2000). Reflective argumentation and decision-making skills in the context of socio-scientific issues are most importantly needed in democratic societies where all citizens are required to make informed decisions about these issues.

The necessity of developing correct science understandings needed to make informed decisions increases the importance of developing skills of argumentation and evaluation of information credibility. However, citizens who do not have the appropriate scientific background, face the challenge of examining the accuracy of information. As a result of the difficulties encountered, people find alternative explanations about socio-scientific issues puzzling (Feihkoll et al. 2016). Moreover, non-specialists consider themselves unable to reflect critically on scientific issues or discourses because they perceive science as authoritative (Norris & Phillips, 1994). Therefore, teaching individuals criteria for evaluating information and accordingly allowing them to reflect on it is currently very essential.

Consequently, in parallel with the scientific literacy and with the revolution of information technology (IT), information literacy is another field of literacy that has to be developed by individuals. Currently, people have access to unlimited information through online resources, e-libraries, and other similar resources. Since adding information on the web is a very easy process, the web contains both reliable and unreliable information (Brem, Russel, & Weems, 2001). Still, people use the Internet to acquire information for individual, academic, or business purposes. Consequently, access to the Internet has the potential to influence the way people make decisions, connect to people all over the globe, and communicate with others in business activities.

Information literacy contributes to the development of many aspects of scientific literacy. First, the recent definitions of scientific literacy include the ability to evaluate scientific reports and develop reasoning skills to make decisions in the context of socio-scientific issues (Karisan & Zeidler, 2017). However, studies show that high school and university students perform poorly when asked to evaluate scientific reports (Norris & Phillips, 1994; Norris et al., 2003). At the same time, skills needed for evaluating the credibility of information are important when conducting research about socio-scientific issues, engaging in argumentation, and making informed judgments and decisions concerning these issues. McDonald (2010) states that:

> Advances in technological innovations, and increasing globalization, require students of the twenty-first century to handle vast, and often complex, sets of information from a variety of different sources. Students are expected to be able to evaluate this information, thus requiring them to engage in argumentation to arrive at evidence-based decisions. (p. 7)

Second, according to Hofer (2004), instructional approaches, which include online website searching and evaluating processes provide opportunities for accessing individuals' epistemological thinking because these practices include evaluation of ideas, coordination of theory and evidence, and justification of knowledge assumptions which are all aspects of epistemological thinking. Hence, engaging in critical evaluation of information credibility and reflecting on the evaluation criteria may serve as a context for reflecting on NOS and activating individuals' epistemological thinking. Changes in the ways of accessing information increase the importance of studying how students examine the credibility of resources, manage the links between theory and evidence, and rationalize their claims (Hofer, 2004).

In summary, teaching students criteria for evaluating the credibility of information critically as well as guiding them to reflect on NOS and argumentation through evaluating controversial information related to SSIs are essential for developing both scientific and information literacy skills. Developing both literacies are indispensable for preparing active citizens who possess the skills needed to deal with the challenges of unlimited and puzzling information available as well as to make informed decisions about controversial social issues through reflective argumentation. Still, Mason et al. (2010) state that learners engage in limited metacognitive reflections when examining the reliability of information and find difficulty in identifying contrasting notions.

Purpose and Research Questions

Studies (Kolstø, 2001; Sadler et al. 2004) claim that NOS understandings are significant and relevant for evaluating scientific information. Several studies (e.g., Brem et al., 2001; Foo et al., 2014; Francke, Sundin & Limberg, 2011; Kovalik et al., 2012; Lin & Tsai, 2008; Mason, Boldrin, & Ariasi, 2010; Porshch & Bromm, 2011; Tsai, 2004; Tsai 2008; Wu & Tsai, 2005; Yaung, Chen, & Tsai, 2013) showed that epistemic beliefs guide students' strategies and criteria for evaluating information. Students with more informed views of the nature of knowledge, and especially the nature of science, use more sophisticated criteria for evaluation (Lin & Tsai, 2008). However, studies regarding improving students' NOS understandings through teaching them evaluative criteria and developing their information evaluation skills by engaging them in alternative information credibility evaluation practices are nearly absent, creating a gap in the knowledge.

On the other hand, evaluating information requires specific argumentation skills for identifying the pros and cons of alternative explanations and evaluating the evidence that is used to defend claims (Braten et al., 2014). According to Hsu, Tsai, Hou, and Tsai (2014), decisions regarding socio-scientific issues require practices such as evaluating, analyzing, and reflecting on the information. Nevertheless, the literature lacks research studies that aim to improve socio-scientific argumentation skills through teaching credibility evaluation criteria and engaging students in critical evaluation of alternative explanations.

Considering the gap of the knowledge in the literature, this research aims to investigate the changes in Grade 7 learners' NOS understandings and argumentation skills after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues Specifically; this research study aims to answer the following questions:

1. How do grade 7 learners' NOS understandings and argumentation skills change after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues?
2. How are alternative information evaluation and argumentation skills related after engaging in reflective discussions from the perspective of FRA?

Rationale of the Research Problem

According to Leung et al. (2015), NOS understandings are essential for guiding individuals who do not have scientific backgrounds to evaluate scientific information published in the media. It is not expected that these individuals, who do not have scientific background knowledge, would be able to evaluate the claims made by experts efficiently (Norris, 1995). However, even if evaluating claims is challenging, individuals can still evaluate scientific information as they develop sophisticated understandings about the nature of scientific knowledge. Several studies (Feinkohll et al., 2016; Kolstø 2001; Kuhn & Weinstock 2002; Norris, 1995; Ryder 2001; Sadler et al. 2004; Strømsø et al. 2011) show that critical evaluations are guided by students' epistemic views. Individuals with more complex scientific epistemologies evaluate information more critically (Feinkohl et al., 2016).

Leung et al. (2015) argue that critical evaluations to check the credibility of explanations may help learners improve their scientific reasoning and their understanding of the nature of scientific knowledge. Feinkohl et al. (2016) maintain that prior studies (e.g., Trautwein & Lu dtke 2007) claim that epistemic beliefs may be developed and shaped by exposing students to opposing information. Ferguson et al. (2012) also suggest that the epistemic cognition of individuals may take place when they are engaged in discussing the opposing beliefs regarding controversial issues. However, research studies that investigate the effect of teaching credibility evaluation criteria and engaging students in critical evaluation of alternative explanations on enhancing students' understandings of the nature of science are almost absent in the literature.

On the other hand, according to Hsu, Tsai, Hou, and Tsai (2014), socio-scientific issues are open-ended and ill-structured. For this reason, they require the use of higher-order reasoning and reflective thinking. As students discuss controversial scientific issues, they need to consider the perspectives of and the solutions suggested by several parties. Therefore, this process of addressing socio-scientific issues not only enables learners to practice evaluating, analyzing, and reflecting on information actively but also engages them in justifying claims or arguments and accordingly making decisions. Yaung, Chen, and Tsai (2013) consider those course activities that include searching, and evaluation of information related to controversial science issues, or socio-scientific issues could be a practical way to bring about discussions and debates on the development of science and scientific knowledge. Braten et al. (2014) suggest that practices such as evaluating information using data provided about the source of information require specific argumentation skills for identifying strengths and shortcomings of the alternative explanations and considering the evidence presented to support the reason. Alternatively, studies investigating the influence of teaching criteria for an information evaluation and evaluating alternative interpretations on the improvement of both understandings about science and argumentation skills about SSI are neglected in the literature.

In the research study conducted by Lombardi et al. (2016), grade seven students evaluated the plausibility of information individually without having any communication with their peers or their teacher. The researchers suggested conducting future research studies that include collective argumentation in parallel to plausibility evaluation to investigate the effect of collaborative argumentation discussions on students' ability to interpret the link between evidence and claims. Therefore, this research study highlights the importance of collaborative, reflective discussions on grade seven students' understanding of the empirical feature of scientific knowledge construction and the argumentation skills of the students.

Significance of the Research Study

Considering the gap in the literature regarding the impact of reflective discussions following teaching criteria for an information evaluation and critical evaluation of alternative explanations on NOS understandings and argumentation skills, this study enriches the literature by providing evidence for the cyclic association between information evaluation skills and scientific epistemology. Following the research suggestion given by Tsai (2004), this study investigated whether or not information evaluation instruction influences individuals' epistemology as epistemology impacts the way individuals evaluate information. Similarly, it enriches the literature as it examines developing socio-scientific argumentation skills as a result of helping students to develop criteria for information evaluation, engaging them in practices such as reading, evaluating, and reflecting on scientific information targeting science-related social controversial issues.

This study goes beyond investigating the effect of students' scientific epistemological understandings on their information evaluation practices; it instead contributes to developing these understandings. Moreover, it introduces a new approach to developing students' NOS understandings. Hofer (2004) highlights the importance of investigating the epistemic development of students during the evaluation of the credibility of alternative explanations and developing interventions for this purpose, which may be used by educators at all levels.

Since the nature of knowledge and information is in continuous change (Franke, Sundin & Limberg, 2011), individuals need to develop a new understanding of the nature of knowledge and approaches to knowledge construction. With the growth of online resources and the extension of digital networking, posting or accessing online information has become a straightforward process. Moreover, individuals are living in "information-rich environments" (Kovelik et al., 2012) and over-rely on the internet, which includes information that is not necessarily validated. The digital information resources affect peoples' lives, choices, and practices (Franke et al., 2011) significantly. Therefore, evaluating the quality of information is not limited to researchers and professionals only, but also is done by any individual or citizen who uses the internet and makes decisions based on online information. Nevertheless, many kinds of research show that people are not trained to evaluate the quality of resources (Amsbary &

Powell, 2003; Metzger, Flanagin, Eyal, et al., 2003). Therefore, this research study draws the attention of teachers and librarians to the importance of developing information evaluation skills of future citizens, leading them to be more critical in using information from the Internet, improving their argumentation skills, and helping them to make more informed decisions.

Even if information evaluation skills are essential for 21st-century learners, the Lebanese curriculum does not include objectives that target the development of information literacy in general and critical evaluations in particular. For this reason, even if students rely heavily on the internet to search for and to acquire knowledge, explicit instruction on information evaluation skills is rarely highlighted at the school level. Many students who are about to graduate and enter universities may not possess the necessary skills needed to be skillful scholars or researchers. Even if the students of this era are digital natives (Prensky, 2001), they barely know how to use information effectively (Foo et al., 2014). Therefore, this study also contributes to highlighting the importance of including information literacy objectives in the Lebanese curriculum and draws the attention of curriculum designers and educational authorities on this issue. Moreover, it encourages teachers and possibly librarians to design lesson plans that include explicit instruction on information credibility evaluation skills regardless of the absence of the objectives in the curriculum.

CHAPTER II

LITERATURE REVIEW

The literature review presented in this chapter provides an overview of NOS in science education and delineates the various perspectives on NOS. It focuses on the FRA framework that is used to design the intervention and analyze the data and summarizes relevant studies that have applied the FRA, whether for textbook analysis or teacher education. Moreover, the review of the literature provides an overview of the role of critical evaluations and argumentation in science education. Furthermore, this chapter provides a review of the literature regarding the importance of essential assessment practices and their interrelationships with NOS understandings and argumentation. The review of literature also presents the role of reflective discussions in science education and summarizes relevant empirical studies that show the impact of reflective discussions on NOS views and argumentation. Finally, it addresses the crucial role of the teacher in running reflective epistemic and argumentation-based discussions. The results of these studies have been systematically examined to investigate the impact of reflective discussion following critical evaluations of information credibility on the development of the participants' NOS understandings and argumentation skills.

Nature of Science

Nature of Science (NOS) is one of the major fields of research in science education as well as in science curricular reforms because it is one of the crucial elements of scientific literacy for informed citizenship (Abd-El-Khalick & Lederman, 2000; Allchin, 2011). Students' NOS conceptions help them to develop an understanding of the process of science and to make more informed decisions regarding controversial social issues. Moreover, NOS views impact students' awareness of the standards and elements of the scientific community, and their ability to develop scientific content knowledge (Driver et al., 1996; McComas, 1998). Educational policy reports and curriculum documents value the role of the NOS and encompass several objectives in its regard (AAAS, 1993; National Research Council, 1996, 2012).

Even if the research studies on NOS are conducted abundantly, there is little agreement about the meaning of NOS (Lederman, 1992; McComas, 1998). Extensive research is conducted to evaluate teachers' and students' NOS views. However, different perspectives and approaches for teaching and learning NOS are developed and implemented in classrooms. The most commonly discussed perspectives are The Consensus View, Features of Science (FOS), and FRA.

The consensus view was developed by Lederman (1992) to examine teachers' and students' views of NOS. In Lederman's perspective, NOS is comprised of seven general aspects of science and scientific knowledge. The consensus model focuses on cognitive and epistemic aspects, including the tentativeness, theory-ladedness, roles of observation and inference, difference between theories and laws, the methodology followed by scientists, roles of creativity and imagination, and social and cultural embeddedness (Lederman, 2007). Numerous empirical research studies are conducted based on the consensus view highlighting the inadequacy in NOS conceptions for both students and teachers and endorsing a reflective and explicit approach for teaching features of NOS (Lederman & Lederman, 2014). Several questionnaires are developed to enhance data collection regarding NOS understandings in the framework of the consensus view (Lederman, 1992).

Matthews (2012) criticizes the consensus view and suggests a new change of terminology and research focus from the essentialist and epistemologically focused nature of science to a more relaxed, contextual, and heterogeneous Features of Science (FOS). As the consensus view concentrates on the general aspects of the nature of science, FOS focuses more on the empirical characteristics of science and considers the practices of scientists. The FOS follows the empiricist viewpoint, such as essentialist thinking and pragmatism (Jho, 2019). FOS extended the consensus view by adding some elements regarding experimental methods of science on the consensus view. These elements are experimentation, idealization, and modeling (Matthews, 2012). Matthews considers experimentation and idealization to be significant in a scientific enterprise and crucial in developing scientific theories. According to Matthews, experimentationand idealization result in models that are important artifacts to predict and explain the natural world.

While the consensus model and features of science primarily highlight the cognitive and epistemic aspects of science and scientific knowledge, modern movements in science education stress the significance of science as a social process. These movements include scientific literacy for all (Roberts & Bybee, 2014), the socioscientific issues framework (Sadler et al., 2007), and the responsibility aspects (European Commission, 2015).

Lately, the consensus view is also challenged by the Family Resemblance Approach (FRA) suggested by Irzik and Nola (2011) and elaborated by Erduran and

Dagher (2014). FRA addresses the critiques of the consensus view and considers the complexity and social embeddedness of science in a more elaborated way. Besides presenting the cognitive-epistemic aspects of science, it addresses science as a social institution more holistically and systematically. The FRA shows the complex interrelations among different aspects of science (see Figure 1). As suggested by Irzik and Nola (2014), in the FRA, the cognitive-epistemic system consists of four categories: Scientific practices, aims and values of science, scientific methods and methodological rules, and Scientific Knowledge. On the other hand, science as a social institution consists of four categories: professional activities, scientific ethos, social certification and dissemination, and social values of science. Erduran and Dagher (2014a) added three categories to include social organization and interactions, political power structures, and financial systems (see the outer ring in Figure 1) and represent science more comprehensively.

The FRA is considered an alternative to the consensus view. Several research studies are conducted to show the effectiveness of the FRA in curriculum and textbook analysis empirically, as well as teacher education. The following section discusses the applications of FRA in science education.

Application of FRA in Science Education

The literature does not include plenty of empirical research studies conducted using the FRA framework. However, this section presents an overview of the studies that used FRA for analyses of curriculum documents (Erduran and Dagher 2014b; Kaya and Erduran 2016; Yeh, Erduran, and Hsu, in press) and textbooks (e.g., BouJaoude et al. 2017; McDonald 2017). Also, it presents other publications based on FRA that include resources for instructional materials (Erduran et al. 2019a, b) and professional development resources (Erduran and Kaya, 2019b; Erduran et al., 2016).

FRA for curriculum analysis. Studies applied the FRA to analyze science curricula (Erduran and Dagher 2014b; Kaya and Erduran 2016). Erduran and Dagher (2014b) evaluated an Irish draft science curriculum and assessment framework using the FRA and examined the NOS coverage in it. The draft included a new component on NOS, which has been considered as a principal feature of science teaching and learning. The results of this examination showed that several elements of NOS are included in the curriculum and assessment specification, yet some of the NOS aspects need further development. The researchers claim that the NOS aspects incorporated in the draft curriculum and assessment specification addressed generally, and NOS components do not necessarily build on a topic or story. The authors believe that "students' engagement in science in general and in learning NOS, in particular, would be enhanced if the various categories are interrelated in meaningful contexts that go beyond disconnected bits of information" (Eduran & Dagher, 2014b, p 344).

Similarly, Kaya and Erduran (2016) explored the potential of the FRA in facilitating curriculum analysis and in detecting the gaps related to NOS in curricula. The researchers analyzed two Turkish science curriculum documents published seven years apart. They also contrasted the Turkish curricula with documents from the USA and Ireland. They evaluated the coverage of FRA categories in the curricula, as well as aimed to show the capability of adapting them to FRA and contributing to curriculum analysis and development. The results demonstrated that all the documents do not show coherence to NOS, and FRA categories were not inclusive simultaneously as narratives. The researchers also found out that FRA categories were not utilized clearly in the curriculum documents to provide a meaning of NOS completely. As the researchers compared the analysis of the Turkish curriculum documents with those from the USA and Ireland, they asserted that there was limited coverage of the categories of professional activities, financial systems, and political power structures in all documents. On the other hand, the social organizations and interactions category was present only in the Turkish curriculum, while the scientific ethos category was only present in the Irish curriculum.

In a recent study, Yeh et al. (in press) analyzed two different versions of curriculum documents, which were published ten years apart in Taiwan using FRA as an analytical tool to investigate the NOS learning standards. The researchers aim to show the role of FRA in exploring the interconnectedness of ideas in curricula and contribute to reforms for the more holistic presentation of NOS aspects in them. The results of this analysis show a shift away from the excessive focus on the cognitive-epistemic system to a consideration of the social-institutional system. The analysis demonstrated an increase in the number of standards targeting aims and values, which are considered as a basis for scientific research and practices. Fewer benchmarks were included regarding scientific knowledge. The researchers specified that these benchmarks were not mentioned coherently as a set of theories, laws, or models. For this reason, they suggest some changes in the NOS standards that follow a more comprehensive and progressing approach to teaching and learning NOS.

FRA for curriculum analysis. Other recent studies have utilized the FRA to analyze school textbooks and study the NOS representations in them. These studies reported several advantages of the FRA to analyzed and identify NOS representations in textbooks. These advantages comprise evaluating NOS ideas in-depth, including neglected NOS aspects in the textbook content, improving the interrelation of the existing NOS aspects more strongly (BouJaoude et al., 2017), and determining the NOS aspects that may be represented in certain topics (McDonald, 2017).

BouJaoude et al. (2017) used an analytical framework derived from the FRA to explore representations of NOS in ninth-grade science (physics, chemistry, and life science) textbooks in Lebanon. The researchers analyzed the entire content of each of the three textbooks to ensure that they consider all the contextual details and NOS components. The findings showed that none of the science textbooks portrayed NOS appropriately and comprehensively. Instead, the NOS representations varied across the disciplines. The physics textbook did not address any of the categories that were examined in the research study. The life and earth science textbook addressed the cognitive-epistemic aspects more frequently than the chemistry textbook. Both the chemistry and the life and earth science textbooks addressed the social-institutional aspects similarly. The textbooks encompassed the social values aspect; however, it failed to address the rest of the aspects under the social-institutional category. The researchers showed the potential of FRA in examining NOS representations across disciplines and suggest specific implications that improve the content of the textbooks to represent NOS better.

In another study, McDonald (2017) explored four Australian junior secondary textbooks to analyze representations of NOS within the topic of genetics. The researcher used the FRA to analyze the representation of the NOS and showed that NOS is addressed multiple times in the textbooks implicitly. The examination of the chapters indicated that they do not include guiding questions or linking statements that help to represent NOS aspects more explicitly and effectively. The researcher demonstrated how the application of the FRA allowed organizing the sections, the science content, the texts, inquiry activities, and questions, as well as to identify and explore the representation of NOS aspects in a more holistic and detailed manner. McDonald (2017) also showed how only certain NOS aspects might be represented in the topic of genetics, while several other aspects might not be considered in a specific context.

FRA in teacher education. Several research studies on teacher education have utilized FRA. Kaya et al. (2019) conducted a funded pre-service science teacher education project at a university in Turkey and aimed to plan, apply, and assess the impact of FRA strategies. The participants of this project, who were a total of 15 female senior Master's level students, took part in a 14-week education intervention. Two sessions were dedicated to introducing NOS theoretically, referring to Erduran and Dagher's (2014a). During the introductory sessions, the participants read a literature review and engaged in small-group discussions. The instructor guided the participants to ponder about how the ideas mentioned in their readings may be applied in teaching practices. During the rest of the sessions, the researcher addressed the aims and values of science, scientific practices, scientific methods and methodological rules, scientific knowledge, and the social context of science. Two sessions were dedicated to each category. In one of these sessions, the participants engaged in discussions, while in the second session, the participants were asked to work in groups and to prepare lesson materials. Then, each group designed science lesson plans using several resources. The researchers designed a questionnaire and conducted interviews to evaluate the impact of the intervention on the pre-service teachers' NOS views. The researchers analyzed the data quantitatively and qualitatively and found out that the intervention had a significant impact on their NOS views. The results showed that the pre-service teachers' views of aims and values of science, methods, scientific knowledge, and social and institutional systems of science improved after the intervention, while their views of scientific practices did not vary.

In the same context, Erduran et al. (2018) described a specific aspect of NOS, scientific practices, and studied the extent this aspect is integrated into a pre-service teacher education program in Turkey. The researchers referred to Erduran and Dagher's (2014 a) benzene ring heuristic (BRH), which combines the epistemic, cognitive, and social aspects of scientific practices into a comprehensive and visual representation. BRH addresses scientific practices such as data, models, explanations, predictions, argumentation, and social certification. The researchers reported results from a funded project that integrated BRH in a preservice science teacher education program in Turkey. They reported the detailed qualitative analysis of preservice science teachers' representations of scientific practices. The results showed that pre-service teachers described scientific practices more holistically after taking part in an intervention that included training through the use of BRH.

In another recent study in the context of the new curriculum on NOS in Ireland, Kelly and Erduran (2018) examined pre-service science teachers' views of the aims and values of science, such as objectivity and empirical adequacy. The researchers presented an overview of the epistemic, cognitive, and social aims and values of science and examined pre-service science teachers' views of these aims and values. The researchers analyzed the data qualitatively and presented the interpretations of two pre-service science teachers of aims and values in science in detail as case studies. The results of this research study indicated that the pre-service teachers considered that novel and critical examination aims were more appropriate for students of higher grade levels.

Both teachers stated that the idea of science aiming to be novel is an aspect that is valued more by older students. They also thought that older students might find objectivity and honesty less significant to them. On the other hand, one of the pre-service teachers thought that, in the context of critical examinations, supporting a specific claim by providing reasons to justify it is more appropriate for the high school students' age level. She considered that younger students are required to develop basic content knowledge of science and do not need to validate their reasoning. Moreover, one of the pre-service teachers stated that older students pay more attention to providing the right answers instead of their conceptual understanding of science because, at this stage, the pressure of scoring better on exams increases. For this reason, this pre-service teacher thought that as the importance of the exams increases, the students become bias regarding experimental work because they develop the tendency of having less experimental errors. The researchers show that Erduran and Dagher's (2014) framework may be utilized in the context of teacher education to engage pre-service teachers in discussions regarding their teaching goals.

Although the above-mentioned research studies show the effectiveness of FRA in curriculum and textbook analysis, as well as teacher education, FRA is condemned for being complex for k-12 students. Moreover, FRA is criticized for not listing aspects of the nature of science and serving as a background (Lederman and Lederman, 2014). As a response to Lederman and Ledernam (2014), Irzik and Nola (2014) argued that the authors had misinterpreted the way FRA is proposed to be utilized.

Critical Evaluations

The importance of including epistemic and conceptual aspects of science in science education is emphasized in the recent educational policy documents in the United States and Europe (AAAS, 1989; EACEA, 2011; NRC, 2012). Traditional science instruction that views “science-as knowledge” is gradually shifting to perceive “science-as-practice” (Christdoulou & Osborn, 2014). Memorizing facts and scientific terminologies instead of understanding science through scientific practices leads to the development of “inert knowledge” as well as makes the learners be passive during instruction (Ford, 2012). Therefore, the tendency to replace declarative instruction with more interactive methods of knowledge construction is increasing. More attention is given to engaging learners in knowledge-generating practices similar to scientists such as argumentation, modeling, discourse, and critique than directly telling them what science is or how it works (Christodoulou & Osborne, 2014).

Justifying and evaluating claims are two of those knowledge-generating practices that have to be incorporated in science instruction as “science-as-practice” (Ford, 2012). The necessity of engaging students in information evaluation practices is also emphasized in the recent educational reform documents such as Next Generation Science Standards (NGSS, 2013) and the National Research Council (NRC, 2012). A framework of K-12 Science Education, which includes the Next Generation Science Standards, states that “critique is an essential element both for building new knowledge in general and for the learning of science in particular” (NRC, 2012, p.44). Critical evaluation is recognized as the ability to differentiate and coordinate evidence with scientific justifications. Evaluation activities promote mature scientific and reflective thinking (Lombardi et al., 2016), as well as link scientific investigations to the process of developing justifications and solutions (NRC, 2012). Developing understanding and skill of credibility evaluation by using specific criteria is necessary for constructing a good understanding of scientific knowledge (Lombardi et al., 2013), perceiving the dynamic nature of scientific knowledge construction (Erduran & Dagher, 2014a), and taking part in procedures of knowledge construction significantly similar to scientists. According to Ford (2012), “the interaction between construction and critique, or proposition and opposition, is fundamental to how science works and how its practices support progress in sense-making” (p. 212).

Critical Evaluations and NOS

Critical evaluations include many aspects of epistemology and its practices. Epistemic practices are defined by Kelly (2008) as “the specific ways members of a community propose, justify, evaluate, and legitimize knowledge claims within a disciplinary framework” (p. 99). Therefore, information credibility evaluation is an epistemic practice performed by scientists. Christodoulou and Osborn (2014) describe these epistemic practices as follows. -

The selection of one set of data over another to count as evidence for a knowledge claim, the preference to a particular methodological approach and research design, or the ways in which empirical results will be presented to the scientists’ disciplinary community to convince them of their significance, are only a few of the choices scientists are required to make during the construction of knowledge claims. At each of these steps, scientists need to make evaluative judgments and critique theirs or each other’s work engaging in the evaluation of knowledge claims, and at the same time, use evidential support to justify their decisions and communicate their views and results in a persuasive manner, regardless of the scientific discipline of which they are part (p. 1277).

Reflecting on knowledge construction is indispensable for critically evaluating information, especially in the context of controversial issues (Mason, Ariasi & Boldrin, 2011). Engaging students in scientific reflective reasoning and epistemic cognitive processes enables them to link evidence to justifications and develop a better understanding of science (Lombardi et al., 2016). According to Lombardi et al. (2016), explicit and reflective instruction of critical evaluations improves students' implicit judgments related to the credibility of information regarding complex and controversial scientific issues about which remarkable gap exists between scientists' and students' knowledge

Influence of NOS understandings on evaluation. Several research studies (e.g., Kolstø 2001; Ryder 2001; Sadler et al. 2004) show the significance of NOS understandings in the evaluation of scientific information. Sophisticated understandings about NOS promote critical interpretations of contradicting explanations regarding scientific issues. Kuhn's evaluative level of epistemological understanding encompasses assessing the quality of scientific justifications using certain criteria for evaluating argument and evidence (Lombardi et al., 2016). Dole and Sinatra (1998) consider epistemic dispositions as the central aspects that influence the degree of cognitive evaluation. Advanced understandings of knowledge and knowledge to enable students to associate alternative explanations regarding contradicting issues and evaluate the potential strength of the evidence in gauging arguments (Kuhn & Weinstock, 2002; Leung et al., 2015).

For this reason, NOS understandings are relevant to the evaluation of socio-scientific issues. In this regard, Sadler, Chambers, and Zeidler (2002) examined the views of high school students regarding the tentative, empirical, and social aspects of NOS and the ways they evaluate the Global Warming controversial socio-scientific issue. Eighty-four students read reports that represented opposing opinions about the causes of Global Warming and responded to an open-ended questionnaire related to NOS and socio-scientific decision-making by writing short texts. Thirty students were interviewed to elaborate their responses on the questionnaires. The researchers addressed the tentative aspect of NOS by providing conflicting viewpoints related to the causes of Global Warming and evaluating the changes in the conclusions. The authors utilized discussions about the economic, personal, and social influences on Global Warming to address the social embeddedness of the scientific knowledge while the empirical basis of scientific knowledge was addressed through the data utilized to support a certain position. The results of this study showed that understanding of several aspects of NOS affects the way students understand, evaluate, and debate contradictory evidence regarding socio-scientific issues. They concluded that conflicting views about SSIs provoked students' thoughts of NOS and developed their knowledge about the ways researchers evaluate contradictory evidence. Furthermore, the intervention increased students' awareness regarding social and personal influences on researchers' judgments.

In the context of the influence of NOS on critical evaluations, Lin and Tsai (2008) examined how high school students' scientific epistemological views are associated with information commitments. Information commitments are the evaluative standards or criteria used to evaluate information. The authors investigated whether or not students' epistemic beliefs influence their evaluative criteria and searching strategies as they read scientific data from Web resources. Results showed that the students who had informed views of the tentative aspect of the nature of science used more advanced evaluative standards to critique the efficacy of the information on the Web. Therefore, they concluded that developing scientific epistemic views through constructivist approaches might lead to better evaluative standards and searching techniques for online information. The authors point to the important scientific epistemic views for engaging students with metacognitive processes in the context of online science information.

In another research study, Yang, Chen, and Tsau (2013) investigated how college students' judgment standards are influenced by their epistemic beliefs when evaluating online sources that address controversial social issues. The controversial issue discussed in the research was the effect of electromagnetic waves on the health of human beings. University students performed web-searching activities after reading news reports and noting their views. The aim of these activities was validating their thoughts. The researchers recorded the path through which the participants navigated the web. Later, as the students were watching their personal web searching procedure, the authors interviewed the participants about the standards based on which they considered online information credible. The researchers used a questionnaire to evaluate the students' epistemic beliefs. The analysis of students' responses showed that students considered information credible mostly according to its strength of the arguments, the availability of evidence, and its authority. However, the examination of the credibility of the provided evidence was rare. The findings of this study reveal that epistemic beliefs related to the authority of the information are correlated with the judging standards. On the other hand, beliefs about learning ability and justification in science influence the number of standards provided to justify evidence.

In a similar context, Brem, et al. (2001) studied the ways students evaluate scientific arguments as they are presented through the Web. Around 80 female students from a single-sex school were introduced by the criteria for evaluating online information. Out of six available web sites, the participants were asked to evaluate three websites and to categorize them as high, moderate, and low in terms of levels of reliability. The websites challenged the students by presenting arguments from several points, lacking details and evidence to support the arguments or including invalid evidence. Later, the participants were asked to reflect on the criteria and to describe them to individuals who are not that informed about evaluation criteria. The researchers concluded that the weaknesses of the students are due to their immature epistemological understandings, their dependence on shallow characteristics of the web sites, their inability to analyze the websites in a systematic manner, and their lack of metacognitive skills.

Finally, to study the influence of NOS on the critical evaluations, Zeidler et al.(2002) studied the connection between secondary and college students' views of NOS as well as the ways they react to the evidence that challenges their opinions about SSI. The participants, who were engaged in small group discussions and reflections about SSI, were asked to support their opinions by answering open-ended questions. Following the participants' responses, the researchers interviewed a selected group of students to challenge their reasoning by asking them questions that activate their epistemological thinking and require more explanation about their beliefs and judgments. Results showed that there were significant differences between the moral and ethical perspectives of college and high school students. Although students disregarded puzzling and contradictory views regarding SSIs, they associated the development of a particular judgment with the availability of evidence related to the issue. Therefore, the researchers emphasized the significance of evaluating views regarding SSI in accordance with the given evidence. The researchers also asserted that reflection on NOS helped students to recognize the cultural and social conditions that affect the process of scientific knowledge construction. Therefore, they highlight the importance of including NOS in instruction to enhance students' reasoning and understandings about SSIs. The authors also emphasized the importance of contextualizing NOS in SSI to develop students' perceptions about the ethical and social issues related to science and engaging them in metacognitive reflections.

Even if several research studies show the significant influence of epistemic views on the abilities of critical evaluation of information, research studies conducted in the field of evaluating science news articles in the media to investigate the significance of NOS understandings in this context are scarce (Leung et al., 2015).

Argumentation

Argumentation is a common practice that promotes the construction of scientific knowledge. Scientists argue about specific issues until they come up to a consensus and release the best conclusion of that era. Therefore, argumentation includes epistemic features. Consequently, the absence of argumentation-based instruction in the science classrooms misrepresents the nature of science.

Moreover, argumentation engages individuals in complex cognitive processes where they have to make a claim, to provide evidence for it, and to consider the counterarguments of their claims. Throughout the argumentation process, individuals may shape their understandings and accordingly make decisions concerning specific issues. According to Osborn (2004), argumentation increases individuals' curiosity, promotes reflective reasoning, and active engagement. Several types of research (Cetin, 2014; Khishfe, 2012) show the positive impact of argumentation on conceptual change, content knowledge understanding, NOS views development, critical thinking, etc. Engaging in effective argumentation and making decisions based on critical arguments are essential aspects of a scientifically literate person (NRC, 1996).

Critical Evaluations and Argumentation

Educational reforms have clearly stated that critique and evaluation are essential elements for argumentation (NRC, 2007, 2012). If argumentation lacks analysis and evaluation, the scientific knowledge construction process is not comprehensive (Ford, 2008). Chen et al. (2016) consider argumentation as 'a series of developed reasoning or explanation activities that occur within or between individuals when they try to convince an audience of the validity of their knowledge claims to reach a mutual agreement" (p. 103). Thus, the researchers define argumentation as 'the interplay between construction and critique involving both an individual cognitive process and a negotiated social act within a specific community' (p. 102). Argumentation involves making a claim, rationalizing it with evidence, negotiating, challenging, and evaluating others in the community until an agreement is reached as a result of debate or discourse.

Mercier and Sperber (2011) state that argumentation is not limited to, developing claims only but involves evaluating other arguments to identify errors and deficiencies. It includes individual cognition and social negotiation to reach a mutual agreement. In this sense, Ford (2012) claims that during argumentation, people produce their arguments and evaluate those of others. As opponents critique a claim, supporters are required to go over their argument and strengthen it with further evidence. In this way, argumentation and evaluation of its validity contribute to the scientific knowledge development process. The publicly accepted scientific knowledge results from the constant critique and evaluation of the validity of arguments originated by individuals.

The scientific community does not directly accept scientific claims. Critics are essential in the process of accepting or rejecting a claim because they demand enough evidence for a claim to be accepted. Opposing a claim is a necessary practice because it shows that the individual makes sense of the claims and the different types of evidence supporting them. Sensemaking or developing an understanding in science encompasses both the ability to develop and evaluating knowledge (Ford, 2012). Once a claim is strongly supported by evidence and is not falsified by the identification of errors, then it is represented as accepted knowledge.

The relation between critical evaluations and argumentation. From the discussion so far, we recognize that critical evaluations and argumentation are highly associated. According to Lombardi et al. (2016), conducting critical evaluations is essential for collective argumentation that is a common practice in the intellectual communities where alternative explanations are competing to be accepted. Information credibility evaluation is a particularly useful practice when dealing with controversial issues because of the need to make judgments related to evidence and alternative explanations. Critical evaluations involve weighing the strengths and weaknesses of evidence and its relation to the claim. Going beyond a shallow critique, critical evaluations gauge and measure the potential of the evidence in justifying the claim and invalidating the alternative explanations. These measurements are performed through the criteria of evaluation and fallibility (Lombardi et al. 2016).

Additionally, argumentation promotes critical evaluations. When multiple alternative explanations are formed regarding a certain issue, learners are required to evaluate the evidence provided for each explanation through experimentation and analytic investigations (Lombardi et al., 2016). The ability to link evidence to claims promotes students' critical evaluations and leads to knowledge development (Erduran & Dagher, 2014). "The practice of argumentation may promote engagement with the processes of knowledge construction and evaluation, which requires the use of criteria for the selection and evaluation of evidence, the creation of counter-arguments, and the provision of justifications (Christodoulou & Osborn, 2014, p. 4). Argumentation discussions and debates promote critical evaluations because, during the evaluation, students question one another and ask their opponents to explain their positions further and justify the strengths of evidence supporting their claims (Chin & Osborne, 2010). Engaging in plausibility judgments of contradictory evidence and collaborative argumentation improves students' scientific reasoning, evaluation skills, and scientific content (Erduran & Dagher, 2014; Lombardi et al., 2016).

Argumentation and evaluation in science education. In science education, argumentation plays the role of an authentic and effective context for enabling students “doing science” instead of “doing the lesson” (Christodoulou & Osborn, 2014). Ford (2012) highlights the importance of operating science classrooms similar to the scientific community. Argumentation is another knowledge-generating practice performed by scientists. During argumentation, ‘key activity of scientists is evaluating which…the alternative does, or does not, fit with available evidence and, hence, which presents the most convincing explanation for [a] particular phenomenon’ (Osborne, 2012, p. 936).

In educational settings, critical evaluations require an assessment of information credibility, understanding of socio-scientific issues, scientific reasoning, and understanding the procedures of constructing scientific knowledge through discussions (Lombardi et al., 2016). “Students who engage in critical evaluation understand that scientific knowledge emerges from collaborative argumentation, which is a constructive and social process where individuals compare, critique, and revise ideas” (Lombardi et al., 2016). If science instruction does not provide the opportunity for the students to critique and evaluate certain scientific claims, they end up finding scientific information authoritative and accepting any opinion and claim that they cannot gauge (Ford, 2012).

Critique and evaluation are neglected in science education (Mercier & Sperber, 2011; NRC, 2012). Research studies show that students find difficulties in critiquing information because they do not possess evaluation skills. Although students often elaborate their arguments, their difficulties are mainly revealed in their lack of ability to recognize and oppose other claims (Chi, 2009; Sadler,2004), analyze exemplifications and validate justifications (Waldrip, Prain & Carolan, 2010), and to review their claims after receiving critiques from others (Berland&Reiser,2011).

It is important to incorporate similar practices in science instruction consistently to overcome the difficulties related to argumentation and evaluation; The time factor of the research studies should be stressed to detect the progress in argumentation skills. Capturing the enhancement of argumentation needs to take place over a certain period. Few lessons targeting argumentation are not enough for recognizing the potential influence of the instruction on argumentation skills. For this reason, this research study will take place over nearly two months.

Evaluation, NOS, and Argumentation in the Context of SSI

Socio-scientific issues (SSIs) are open-ended problems or dilemmas that are ill-structured and include several viewpoints and explanations (Sadler & Zeidler, 2005). One of the important aspects of scientific literacy is the engagement of students in SSI discussions (NRC, 1996). The science education literature addresses the significance of SSIs in promoting evaluations, argumentation, and NOS understandings.

According to Karisan and Zeidler (2017), “important elements of SL [Scientific Literacy] include the ability to analyze, synthesize and evaluate information, consider multiple perspectives and lines of reasoning while examining scientific evidence, confronting ethical issues, and understanding connections inherent in socio-scientific issues” (p.140). Thus, leaning science in the context of SSIs provides the opportunity for learners to evaluate different perspectives, engage in critical reasoning, practice decision making, gauge and argue about contradictory scientific claims, as well as to develop moral and ethical values regarding controversial social issues (Zeidler, 2014).

In a similar context, Sandoval and Cam (2011) examined the judgments provided by elementary students regarding epistemic levels of justification in assertions that develop a causative association between variables. The authors aimed to investigate the preferred criteria of the students used in judgments. They questioned if the students consider the strength of the evidence, the reliability of the tools used, or the trust in the credentials of the author when judging a certain assertion. The researchers considered that improvements in the epistemology are also enhancements in cognitive processing. They assume that cognitive processing does not occur only through explicit NOS instruction or inquiry-oriented instruction but requires that instruction be designed with the aim of activating students' beliefs to ensure cognitive development. The findings revealed that students prefer empirical types of evidence the most and consider them as the most important factors for reliability judgments. The students depended on judging the credibility of mechanisms, also when the information provided seemed questionable. Making judgments based on the authority was the least preferred criteria for judgments, and it was often associated with the plausibility of the justifications. The researchers concluded that the two epistemological aspects triggered during decision making about causal claims are the availability of evidence and the reliability of the mechanisms.

In another very relevant research study, Osborne, Erduran, and Simon (2004) found SSIs essential for targeting both argumentation and decision-making. Several studies show the positive influence of SSI interventions on the development of students' argumentation skills (e.g., Dole et al. 2003; Zohar & Nemet, 2002). According to Sadler (2011), SSIs serve as an effective context to enhance students' argumentation when the intervention includes support given by the teacher, reflective discussions, or explicit instruction of argumentation. Also, Khishfe (2012) studied how high school students' NOS views are related to their argumentation skills as they are addressed in socio-scientific contexts. The controversial social issues discussed during the study included Genetically Modified Food (GMF) and Water Fluoridation. The results of this study showed that the development of strong arguments is highly correlated with NOS views. Participants with informed views of NOS were able to develop better arguments and make counterarguments clearer. On the other hand, students with naïve views failed in making rigorous arguments and in providing validations to support their position. Moreover, the majority of the participants who possessed naïve views of NOS before the intervention showed significant improvement in their views after the intervention. Additionally, considerable improvement was observed in the participants' argumentation skills.

Using SSIs in teaching is considered as an authentic context for improving students' understandings about NOS (Collins & Pinch, 1998) because it connects morals and expectations related to NOS (Matkins & Bell, 2007). Zeidler et al. (2002) studied the relationship of students' understandings of NOS and the way they respond to data that oppose their views concerning controversial social issues. The participants addressed a socio-scientific scenario related to animal rights. The outcomes showed that when students debated certain moral and ethical problems, their NOS perceptions were reflected in their responses. However, students' arguments were constructed based on their personal beliefs and estimations and were lacking the support of significant scientific proofs.

Similarly, Sadler et al. (2004) studied how the NOS understandings of high school biology students were related to the ways they interpret and evaluate opposing evidence concerning a socio-scientific issue related to global warming. The authors gathered information about students' NOS views and decision-making. The results revealed that the majority of the students developed understandings about the tentative and social aspects of NOS. A small number of students still showed naïve understandings regarding the empirical aspect of NOS. The authors found that the most considerable aspect which affects students' thinking and argumentation is the social aspect of NOS. In a similar context, Eastwood et al. (2012) investigated the influence of both SSI-driven and content-driven contexts for explicit-reflective NOS instruction on high school students' NOS understandings. Four classes were divided into two groups, each of which received NOS instruction either in SSI-driven or content-driven explicit reflective NOS instruction. The analysis of the participants' responses to the VNOS open-ended questionnaire at the beginning and end of the school year showed that both groups had remarkable improvements in most of NOS understandings. However, the participants who received the NOS instruction in the SSI-driven were able to utilize certain examples to explain their views regarding the social and cultural aspects of NOS. The results of this study show that SSI-based instruction improves students' NOS understandings. Contrasting Zeidler et al. (2002), Sadler et al. (2004) and Khishfe (2012), Bell and Lederman (2003) found that NOS views possessed by the participants do not considerably influence their decisions regarding SSIs in any of the groups as they studied how NOS understandings influence decision-making processes about socio-scientific issues. The participants mostly relied on personal, social, and political facets when thinking about the problem. They also found that views about the empirical aspect of NOS influenced participants' reasoning insignificantly.

Evaluation as a Social Activity

Critical evaluation of science media reports is indispensable in modern society because of the prevalence of news and information digital sources. The ability to search for and evaluating information from the media is as essential as learning scientific content knowledge. Moreover, when individuals critically evaluate scientific information presented in the media, their learning about the nature of science is enhanced, which is as important as learning scientific content. Several studies show that high school and university students do not possess the required skills for evaluating scientific information in the media (Norris et al. 2003; Norris & Phillips 1994). The results of these studies revealed that students have the tendency to find information about the media reports as true and certain. Consequently, people with weak scientific backgrounds find scientific discussions authoritative and imposing (Lueng et al., 2015). Information evaluation skills boost the confidence of non-scientists in reading, understanding, and distinguishing statements made by scientists.

Social epistemology refers to scientific activities that are embedded in the community. These activities include working collectively to share information, findings, and opinions, as well as engaging in critical discussions in harmony with epistemic criteria (Christodoulou & Osborn, 2014). Leung et al. (2015) address the notions of 'science-as-society' and 'science-in-society.' First, science-as-society' refers to the scientific community in which scientists cooperate and build a certain culture. Scientists validate the information by reviewing the results and conclusions of other scientists. They negotiate their findings and try to reach consensus in the case of diversity in conclusions. Practices such as peer-reviewing, collaborative research, and debates reduce subjectivity and bias, as well as increase the possibility of accepting information for publishing or putting it in practice. Individuals accept information generated by scientists more confidently if they understand the approaches utilized by science experts to construct and validate new knowledge. Second, 'science-in-society' refers to the relations of scientists with members of the society who are not part of the scientific community.

Moreover, it refers to the association of science with political, social, economic, and religious factors in society. That is, science is practiced in several societal contexts. Socioeconomic, political, philosophical, and religious factors are influenced by scientific knowledge and practices. Therefore, as non-scientists recognize these factors related to science and society, they evaluate scientific information more effectively.

Understanding scientific knowledge construction as a social activity is vital for assessing the credibility of science news and reports. As individuals in a society highly dependent on information generated by scientists, scientists also depend on knowledge generated by other scientists' to construct hypotheses, experiments, and analyses. Therefore, developing knowledge about how scientists communicate in the process of scientific knowledge construction is crucial for making effective critical evaluations (Norris et al., 2003). Developing informed views about NOS prepares non-scientists to evaluate information more effectively. Since citizens do not have background knowledge about science as sophisticated as those of the scientists, critical evaluation of the information is a highly essential task required from the non-scientists.

Reflective Discussions as Scientific Practice

The significance of incorporating reflective elements in teaching nature of science lies in making learning more meaningful and useful. Baird (1998) claims that if students are encouraged to ask and answer evaluative questions, then the cognitive and affective outcomes of learning improve. In the context of science education, Kuhn and Pearsall (2000) consider metacognition essential in developing scientific understanding. They write: “An essential epistemological requirement of scientific thinking is to be clear regarding the sources of one’s knowledge – knowing how one knows” (p. 127). Reflection in a group context, in addition to contributing to meaningful and effective learning, is significant from a social view of learning (Gage & Berliner, 1998). Reflective discussions contribute to students’ learning from each other, thus making the nature of science instruction even more explicit.

In this regard, DeSchrijver, et al. (2016) emphasize the significance of engaging in reflective discussions and describe these discussions as ‘complex intellectual practices.’ The authors highlight the important role of reflective discussions, especially about NOS, in visualizing abstract concepts, as well as developing conceptual understanding through engaging in metacognitive thinking about science. As individuals think aloud to make connections between knowledge and models, as well as examples and experiences, they undergo conceptual change.

During reflective discussions, thoughts are directed by general and focus questions that enhance metacognition and engage students in epistemic practices and argumentation (DeSchrijver et al., 2016). Considering the positive impact of argumentation discourse and interactions using epistemic criteria and evidence evaluation in generating knowledge, Christodoulou, and Osborn (2014) raise the issue of the quality of classroom talks, the degree of including epistemic and argumentation aspects in discussions, as well as the efficacy of teachers in leading such discourse.

Nielsen (2013) suggests including communication aspects in epistemology because they are the bases of constructing and extending knowledge. When learners have advanced understandings about science as knowledge and science as a way of knowing, viewing communication and discourse as a scientific method for knowledge construction would be easier. Scientific knowledge is shared because constructing knowledge needs communication and cooperation. Kuhn (1970) describes communication in science as the practice of persuading and aiming to convert the notions of the other party. Linguistics plays an important rhetorical role in science because talking to and persuading others are scientific practices (Nielsen, 2013). For scientists to convert their views, they need ‘‘good reasons for being persuaded’’ (Kuhn 1962, p. 199). The scientists aim to persuade other researchers that their research study is accurate and valid (Nielsen, 2013). That is, they need to convince others that their findings are confirmable because they have used reliable methods and evidence.

Another common practice of communication is engaging in discussions with scientific literature and representing work that is directed by already existing published texts aiming for publishing new text to share knowledge (Nielsen, 2013). Scientists express their support or opposition to scientific claims by writing and publishing their opinions and findings. That is, besides oral discourse, scientists communicate through their publications such as books, reports, and articles. These publications represent central resources that provide evidence for communication among researchers. Therefore, reading, evaluating, and justifying these pieces of information are important for understanding the knowledge that scientists are sharing.

Reflective Discussions on NOS and Argumentation

The science education literature reveals the importance of including reflective elements in science instruction to address NOS in an explicit manner to intermediate school learners (Carey et al., 1989; Khishfe & Abd-El-Khalick, 2002). Engaging in metacognitive practices and reflective discussions make learning effective, purposeful, and meaningful (Baird, 1988; Kuhn & Pearsall, 2000). Moreover, engaging in the reflection within a group makes NOS more explicit and provides an opportunity for students to learn from each other. Changes in the nature of discussions are facilitated when the teacher incorporates reflective epistemic operations, such as justification and evaluation, in the science classroom discourses and engages them in epistemic practices (Christodoulou & Osborne, 2014).

Sandoval and Morrison (2003) highlighted the importance of engaging learners in epistemic discourse. Epistemic discourse includes engaging learners in discussions during which they argue about why and based on what criteria they support a certain justification as well as explain the importance of evidence in their justifications. Christodoulou and Osborn (2014) consider the evaluation, comparison, and justification as effective practices for promoting epistemic discourse in science classrooms. They enable learners to perceive science as epistemic practice, as well as to appreciate the role of these practices and discourse in the process of scientific knowledge construction. In reflective discussions, when teachers ask learners to justify and explain their answers, the learners go beyond providing claims to backing them up with justifications (Ford & Wango, 2012).

In science education, argumentation is highly associated with epistemic discussions. Argumentation should be viewed as negotiation and not just an exchange of opinions where the students engage in discourse and evaluate errors to come up with evidence-based arguments at the end of a teaching sequence (Chen et al., 2016; Nussbaum & Edwards, 2011). Discussions about the nature of knowledge and knowing, which are promoted through argumentation practices, enable students to consider argumentation as a practice for generating knowledge instead of accumulating facts (Christodoulou & Osborn, 2014). Ford (2012) addresses the ways of making sense of scientific information and suggests that argumentation is an approach that facilitates sense-making. Scientists understand many phenomena while they take part in argumentation procedures. Therefore, argumentative practices and discourse are the foundation of scientific claims.

Importance of writing along with discussions. Discourse and communication are essential practices for scientific knowledge construction (Ford, 2012). However, according to Aufschnaiter, Erduran, Osborne, and Simon (2008), including writing, along with discussions, is a more effective method of enabling learners to develop advanced levels of reasoning and conceptual knowledge. Arguing orally only allows individuals to clarify already existing knowledge but not to generate new knowledge (Aufschnaiter et al., 2008; Yore and Treagust, 2006). Writing during argumentative discourses is important because it allows the learners to evaluate and modify their thoughts in their working memory and go beyond writing down their talk. Talk is essential for expressing knowledge. However, writing provides the opportunity to operate, associate, and integrate knowledge. Therefore, talking and writing complement each other in fostering cognition and developing knowledge during argumentation

(Chen et al., 2016). When talking and writing are done independently, they help in recording and displaying knowledge, and require lower cognitive functions such as remembering and describing. On the other hand, when writing and talking are performed interdependently, they serve as tools for integrating, analyzing, evaluating, and reflecting, which require higher cognitive functions (Yore & Treagust, 2006).

Chen et al. (2016) studied the influence of talk and writing on the students' participation in knowledge construction and evaluation of arguments. For this purpose, they developed a framework that encompasses four patters: talk only, writing only, talk and writing in sequence and talk and writing at the same time. The researchers analyzed the students' knowledge developed over time by using an in-depth analysis of a Knowledge Development Trajectory and the constant comparative method. The results of this study showed that engaging students in the evaluation of arguments improved their cognitive functions as they started talking and writing in a more sophisticated manner. Additionally, this study shows that when talk and writing are performed simultaneously during the evaluation, the students criticized more effectively and successfully. Therefore, talk and writing are essential language skills that facilitate argumentation and promote scientific knowledge development (Nussbaum & Edwards, 2011; Yore & Treagust, 2006). The combined effect of talk and writing ensures higher levels of cognitive processes (Chen et al., 2016) and particularly analogical thinking (Mercier & Sperber, 2011). Based on the literature, in this research study, the participants were asked to write down their explanations before and after engaging in reflective discussions.

Role of teachers in implementing reflective discussions. The ability of teachers to implement reflective and argument-based discussions is crucial for engaging learners, ineffective practices, and discourse (Ford, 2012). The effectiveness of reflective discussions depends on teachers' efficacy to facilitate a discourse through effective questioning techniques that expand students' reasoning, promote reflections, ask for explanations and, lead to hypothesis formulation and argumentation (DeSchrijver et al., 2016). The teachers should be trained not only to teach science through argument-based instruction but also to talk about science in the context of argumentation. During effective reflective discussions, the teacher does not offer direct answers but facilitates discourse that directs students' thinking. When the teachers, who lack the skills of running an effective argumentation discussion, are the one who talks and evaluates in the classroom, the learners are not encouraged to learn how to critique and evaluate and are not allowed to understand the role of critique in the process knowledge construction (Ford, 2012). Science teachers are expected to model epistemic practices and discourse as well as to engage the learners in them (Ford, 2012). Consequently, science educators need to focus on teacher professional development programs to ensure that they provide the necessary experiences so that teachers master the abilities to design and teaching argument-based lessons, as well as develop the skills of questioning to run discussions in which arguments and counter-arguments are constructed (Christodoulou & Osborn, 2014).

CHAPTER III

METHODOLOGY

This chapter presents the methods used to study the effect of reflective discussions following alternative information evaluation practices on grade seven participants' NOS understandings and argumentation skills in the context of socio-scientific issues. Throughout the study, changes in the participants' understandings of NOS, as well as their ability to develop an argument, are tracked. This chapter describes the design, participants, school context, intervention, data collection instruments, and data analysis guided by the following research questions:

1. How do grade 7 learners' NOS understandings and argumentation skills change after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues?
2. How are alternative information evaluation and argumentation skills related after engaging in reflective discussions from the perspective of FRA?

Research Design

A qualitative research design was used for the purposes of this research study since qualitative studies focus more on the process and try to understand "the meaning people have constructed" in natural, real-life contexts (Merriam, 1998, p.6).

Participants

Participants in this research study were sixteen grade seven participants, with middle and high socioeconomic status and diverse religious and cultural backgrounds who were enrolled in an urban co-educational private high school in Beirut. Out of the four grade seven sections, the researcher selected one section (7D) to be part of this research study. In this section, out of the twenty-two participants, sixteen participants took part in the research because four students disagreed to participate, and the researcher excluded two other students because of their absences. Out of these sixteen participants, 7 were females. The average age of the participants was 11 years old. These participants did not have any experience with formal NOS and argumentation instruction before the study. During the previous years, the students have not been explicitly taught NOS and argumentation skills. The development of NOS understandings and argumentation skills were included in the chemistry, physics, and biology unit plans, particularly for the purpose of this research study.

The school was selected based on ease of access and convenience. The classes were heterogeneous because the school ensures that students of mixed abilities and gender are included in the same classroom. Considering that the participants were not be randomly selected from a large population, generalizing the findings of this study is limited to schools with similar contexts.

The researcher ensured that the study respects the requirements of the university Institutional Research Board (IRB) and thus did not cause harm to the participants. The researcher informed the participants that they were going to take part in a research study. The participants remain anonymous throughout the study.

School Context

This K-12 co-educational private school follows the Lebanese curriculum. The language of science instruction is English. The study took place during biology, chemistry, and physics lessons, which were taught by the same teacher. The researcher was the parallel teacher of the collaborating teacher. The researcher taught sections 7A and 7B, while the collaborating teacher taught sections 7C and 7D.

The participants took two periods of biology as well as one period of each of physics and chemistry per week. Each period is fifty minutes long. The participants used physics, chemistry, and biology e-textbooks, which are prepared by the school's Digital Curriculum Development (DCD) department. The content of the e-textbooks is adapted to the Lebanese curriculum. The e-textbooks reflect Lebanese culture and social values. In the classroom, each participant has an iPad, on which the e-textbooks are posted.

Intervention

This study was conducted at the end of the academic year's second term. At this time, the grade seven participants had completed three units in parallel: "Heat" in physics, "Animals' Alimentary Behavior and Digestion" in biology, and "Mixtures" in chemistry. Covering these units ensured that students have the prerequisite knowledge needed to address the socio-scientific issues selected for this study that address climate change, electromagnetic wave pollution, water fluoridation, and animal testing.

Planning and Producing the Instructional Materials. The following section provides an overview of how the researcher prepared the descriptions of the socio-scientific issues, MEL-diagrams, and MEL-diagram questionnaire.

Brief description of the socio-scientific issues. In this study, the participants read and familiarized themselves with four socio-scientific controversial issues (climate change, water fluoridation, animal testing, and electromagnetic wave pollution). To do so, the participants read short scenarios, which briefly introduce controversial issues. The researcher adopted the water fluoridation scenario from Khishfe (2014). The

researcher prepared three other scenarios about climate change, animal testing, and water fluoridation, similar to that of water fluoridation. These brief descriptions of the controversial social issues are represented in Appendix I.

MEL-diagrams. An adapted version of an instructional scaffold called the Model-Evidence Link (MEL) diagram (see Figure-2) was used to assist the participants in evaluating information as well as in reflecting on both NOS aspects and argumentation components. According to Lombardi et al., (2016, p. 1394), "The MEL diagram is an instructional scaffold built upon the idea of epistemic criteria, and is designed to make the scientific practice of critical evaluation explicit through model-based reasoning and argumentation."

The MEL diagrams consist of two types of boxes: Model and Evidence. Each MEL-diagram includes two Model boxes and several Evidence boxes. The Model boxes represent the alternative explanations given regarding a socio-scientific issue, while the Evidence boxes provide data that support or contradict the explanation of the Model boxes. Some Evidence boxes may be unassociated with the Models. For instance, the MEL-diagram of Figure-2 represents the two alternative explanations given regarding climate changes in the boxes named as Model A and Model B. Model A includes the position of those who consider that climate change is caused by human activities, while

Model B includes that of who believe climate change is due to the changes in the amount of energy released by the Sun. On the other hand, for example, data mentioned in the Evidence-1 box strongly supports the position represented in Model-A as it states that the greenhouse gases produced through human activities have increased the atmospheric temperature in the past 50 years. The information provided in the Evidence-2 box contradicts Model B as it asserts that the temperature of the Earth is increasing even though the amount of energy received from the sun is decreasing. Evidence-4, which shows the relation between solar activity and global temperature before and after the industrial revolution, is not associated with Model B.

Besides the MEL-diagram that was adopted from Lombardi et al. (2016), the researcher prepared three other MEL diagrams using information retrieved from seven online articles that represent the alternative explanations of proponents and opponents regarding the other three socio-scientific issues used in this study. First, the MEL-diagram about water fluoridation socio-scientific issue was prepared using two online articles entitled *"Facts about Fluoridation"* and *"How seriously should we take the Fluoride Controversy?"* which are posted on *Live Science* and *Public Radio International (PRI)* websites respectively. Second, to prepare the MEL-diagram about animal testing controversial issue, the researcher referred to three online articles titled *"Defending Animal Research," "Experiments on Animals: Overview"* and *"Animal experimentation: A difficult issue"* which are published by *American Psychological Association's* (APA), *People for the Ethical Treatment of Animals* (PETA) organization's and *BBC news* website respectively. Finally, the researcher referred to online articles entitled *"Nonsense about the Health Effects of Electromagnetic Radiation"* and *"Debate Continues on Hazards of Electromagnetic Waves,"* which are posted by *Science-based Medicine* and *New York Times* websites respectively, to prepare the MEL-diagram about the electromagnetic wave pollution controversy. The URL links of the websites used to prepare the MEL-diagrams are listed in Appendix-II.

The purpose of converting online articles into MEL diagrams was to simplify the ideas represented in online articles, to facilitate the evaluation of information and to assist the intermediate school participants in linking the alternative claims to evidence. The online articles are sophisticated for middle school participants in terms of language and structure; consequently, the researcher selected the relevant information from the online articles and prepared the MEL diagrams. The participants read the data provided in the MEL-diagram boxes to familiarize themselves with the main alternative explanations given regarding the same controversial issue.

MEL-diagram questionnaire. For the purpose of this study, the researcher adapted the MEL-diagrams by adding a questionnaire to each MEL, which targets NOS, and argumentation after the explanatory part of the MEL diagrams. The complete MEL diagrams are presented in Appendix III. After completing each of the MEL-diagrams and participating in reflective discussions, these questions mainly tracked the changes in the participants' understandings of NOS as well as their ability to state a claim, support it with evidence and recognize the counterargument of their claim.

Preparing the teacher. Before the intervention, the researcher had one-on-one meetings with the teacher to introduce the socio-scientific issues, the criteria for information evaluation, the FRA wheel, and the meaning of its categories, MEL-diagrams and the components of Toulmin's argumentation model. The researcher also asked the teacher to read articles to be further acquainted with topics associated with the study. Moreover, the researcher asked the teacher to watch video samples of reflective discussions about NOS and argumentation that provide guidelines for running effective discussions. The researcher explicitly explained the instructional strategies needed to apply the intervention and, provided the lesson plans and the worksheets of MEL-diagrams. The detailed lesson plans are represented in Appendix IV.

The procedure for implementing the study. This section describes the procedures used to implement the study. The procedure starts by teaching the participants the information evaluation criteria and components of developing informed arguments as well as training them to use MEL-diagrams to facilitate the evaluation of information. Following the instruction and the practice on MEL-diagrams, the participants read short descriptions about four other socio-scientific issues and completed MEL-diagrams addressing them.

After the completion of each MEL-diagram, the participants engaged in reflective discussions addressing NOS and argumentation in the context of SSIs. The procedure ended as the participants were asked to respond to a questionnaire that addresses both their NOS understandings and their ability to develop an argument. Table 1 presents a general overview of the intervention period and the instructional activities. The lesson plans of this study are further described in Appendix IV.

Teaching using the instructional material. The following section describes the instructions given to the participants before completing the MEL-diagrams and engaging in reflective discussions. Before practicing for completion of the MEL-diagrams, the teacher asked the participants to read about the description of the controversial issue, clarify the criteria that were used to evaluate the credibility of information, and asked participants to evaluate information based on these criteria. Later, the teacher explains three components (Claim, Evidence, and Counterargument) of Toulmin's to the participant

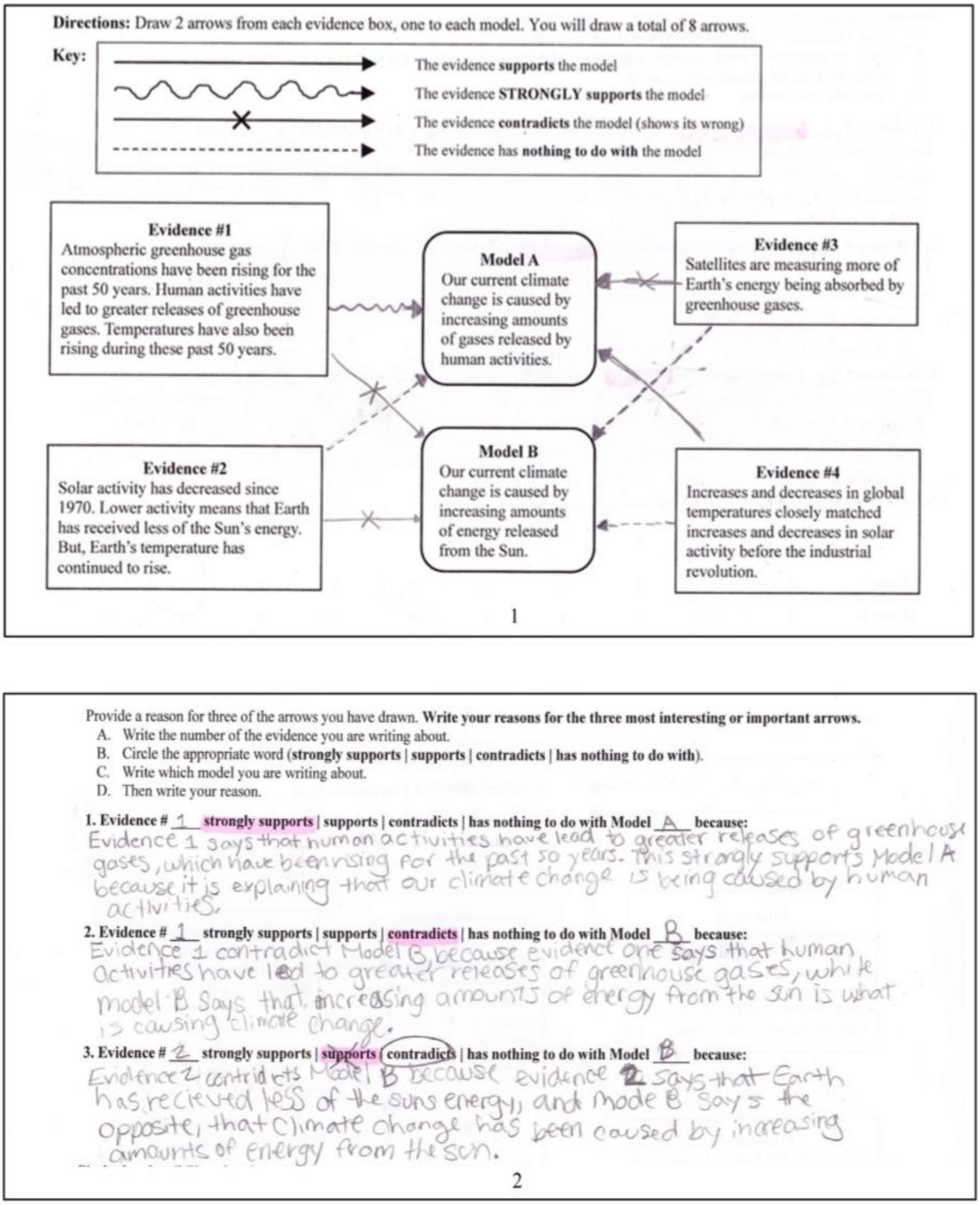

Figure 2. A sample of MEL-diagram (Lombardi et al., 2016, p.1399).

Table 1

Overview of the Intervention Period

Week	Duration	Activity	Summary
46	50 minutes	Credibility Evaluation Criteria and Toulmin's Argumentation Model	Information credibility evaluation criteria and Toulmin's argumentation components will be defined Evaluation of climate change controversial articles in terms of currency.
	50 minutes	Climate Change	Practice completing climate change MEL-diagram
47	50 minutes	Climate Change	Reflection discussions on climate change Completion of MEL-diagram questionnaire
48	50 minutes	Animal Testing	Completion of animal testing MEL- diagram
	50 minutes	Animal Testing	Reflective discussion on animal testing Completion of MEL-diagram questionnaire
49	50 minutes	Water Fluoridation	Completion of animal testing MEL- diagram
	50 minutes	Water Fluoridation	Reflective discussion on water fluoridation Completion of MEL-diagram questionnaire
50	50 minutes	Electromagnetic Wave	Completion of animal testing MEL- diagram
	50 minutes	Electromagnetic Wave	Reflective discussion on electromagnetic wave Completion of MEL-diagram questionnaire

Criteria for evaluating the credibility of information. At the beginning of the intervention, the teacher highlighted the importance of evaluating the credibility of information critically and explicitly introduced two criteria for evaluating the credibility of information: "Currency" and "Accuracy." The "currency" criterion refers to how up-to-date is the information, while "accuracy" refers to how valid, well-researched, and supported by evidence is a piece of information. The currency criterion of information evaluation reflects the novelty aspect of the nature of science, while the accuracy criterion reflects the validity of information or the empirical nature of scientific information. The changes in the participants' understanding of the tentative and empirical nature of scientific knowledge, in parallel to many other NOS categories of FRA, was investigated throughout the intervention.

Evaluating the credibility of information. After the participants got familiar with the evaluation criteria, the teacher displayed the online articles that were used to prepare the MEL-diagrams in the classroom and asked the participants to highlight the date of publication of each and to explain the "currency" criteria of credibility evaluation. The teacher clarified that the seven articles are summarized and simplified to prepare the "Evidence" boxes of the MEL-diagrams. Two or three online articles are utilized to prepare the MEL-diagram of each socio-scientific issue. One of the articles presents the position of the proponents while the other article(s) presents the alternative explanation given regarding that particular SSI. The evidence or data that support the claims (Model) of the authors mentioned in these online articles are included in the "Evidence" boxes. To evaluate the socio-scientific claims in terms of the "accuracy" criterion, the participants were asked to complete the MEL-diagrams.

Since the climate change MEL-diagram is retrieved from Lombardi et al. (2016), and the sources of information used for preparing this MEL-diagram are unknown, the researcher selected two online articles that represent the position of individuals who consider that climate change is caused by the increase in the sun's energy and the position of those who believe that climate change is caused by increase in human activities. These articles also include similar evidence to support the different claims, as mentioned in the climate change MEL-diagram. The purpose of selecting these online articles is to give the participants the opportunity to practice evaluating the sources in terms of currency. The first online article is entitled "*Climate and Earth's Energy Budget*" and posted on *NASA Earth Observatory* website, while the second online article is entitled “*A Blanket around the Earth*” and posted on *NASA Global Climate Change* website. The URL links of these online articles are listed in Appendix II.

Argumentation using Toulmin’s model. According to Jiménez-Aleixandre and Erduran (2007), argumentation is facilitated when epistemic criteria are used to evaluate scientific information in the classrooms. Critical evaluations through epistemic criteria are particularly significant for checking the credibility of evidence regarding a claim in the context of the socio-scientific issues, thereby affecting the way individuals argue or defend a certain position. Apparently, MEL diagrams encompass the components of Toulmin’s Argumentation model (see Figure-3). The model consists of six components (claim, data, warrants, qualifiers, rebuttals, and backing) for developing a persuasive argument. A claim is a statement that asserts that a particular position is true. Data is the evidence used to support the claim. Warrants are the statements that link the data to the claim and explain why data supports the claim. Qualifiers are statements that express the relative strengths of the warrant that is supporting the claim. Rebuttals are counter-arguments that indicate the conditions in which the argument is not valid. Backings are statements that justify that the warrants are true in the same way that data support the claim.

Out of the six components of the argumentation model, this study focuses on only three components: Claim, data, and counter-arguments. These three components are selected because understanding claims, evidence and counter-arguments are more appropriate for the participants’ age group and mental abilities compared to the other components of argumentation. Backings, qualifiers, and warrants are more complex components, which may not be easily understood by grade seven participants. During the practice of completing the MEL-diagram, the teacher highlighted the argumentation components and linked them to the MEL-diagrams. The “Model” represented in the MEL-diagrams refers to the “Claim” of Toulmin’s model, which is a position regarding the socio-scientific issues. The evidence provided to support the positions refers to the “Data” component of Toulmin’s model. Finally, the two alternative explanations represented by the opponents and proponents (Model A and Model B) of the same socio-scientific issue represent the “counterargument” component of Toulmin’s model. The evidence provided includes data that oppose the claims stated in each model. Therefore, the statements that oppose a certain position or a model were referred to as the counterargument component of Toulmin’s model of argumentation.

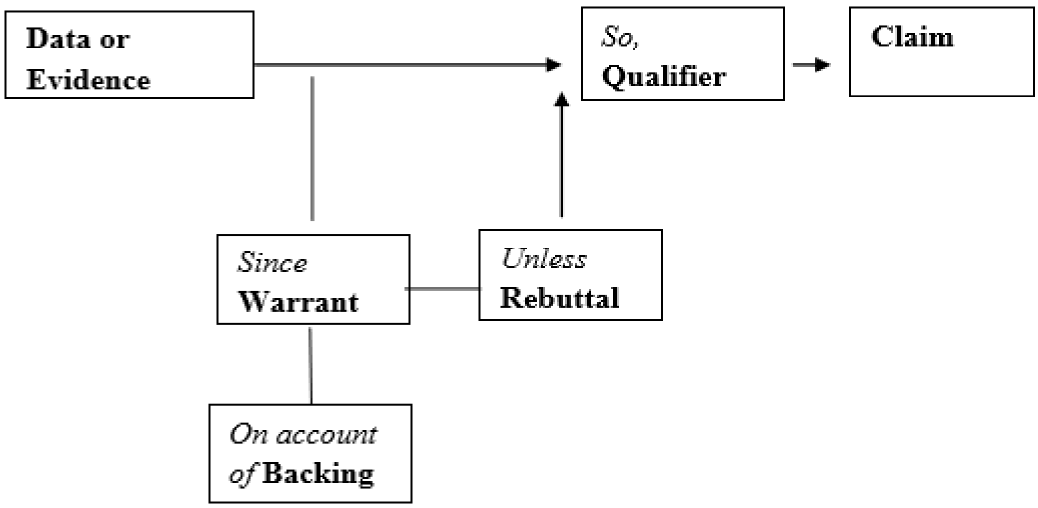

Figure 3. Toulmin’s argumentation model (Toulmin, 1958, p.104).

Practice for completion of MEL- diagrams. At the beginning of the practice**,** the teacher asked the participants to read the scenario that describes the controversial issue related to climate change to get informed about the alternative explanations**.** Then, he assisted the participants in completing the first MEL-diagram (“Climate Change”), which was used as a practice. During the practice, the teacher reviewed the criteria for evaluating the credibility of information and explained the requirements for completing the MEL-diagrams. The teacher explained that the completion of the MEL-diagrams consists of three stages. The first stage is drawing arrows to link evidence to the models. The second stage is completing the explanatory part by explaining why a piece of evidence is linked to a model in a particular way. The third stage is responding to the questionnaire, which targets NOS and argumentation. The first two stages are completed before the participants' engagement in reflective discussions, while the completion of the questionnaire is performed after the reflective discussions.

The teacher gave directions and explained the meaning of each type of arrow that had to be drawn to link the evidence to the models. The purpose of drawing arrows of different types is to show how strongly the evidence is related to the claims as well as to highlight how the credibility of a claim is related to the availability and the quality of evidence. Straight arrows show that the evidence supports the claim. Wavy arrows indicate that the evidence supports the claim strongly. A straight arrow with an "X" in its middle means the evidence refutes the claim. Dashed arrows mean that the evidence is not related to the claim. The shapes and the meanings of the arrows are represented in the MEL-diagrams (Figure-2).

After linking the evidence to the models, the teacher clarified how to complete the second stage of MEL diagrams, which is the explanatory part. In this stage, the participants were asked to choose three model-evidence links and to justify the reason for drawing that specific shape of arrows. Asking participants to write down their elaborations regarding their ideas about the relation of evidence and arguments before engaging in reflective discussions provides the opportunity for associating and integrating knowledge. This enables participants to engage in the reflective discussions more effectively because, based on the literature, individuals engage in higher levels of cognitive processes when writing and talking take place in sequence (Chen et al., 2016).

Completion of the MEL diagrams. Before the completion of the MEL-diagrams, the teacher asked the participants to read the scenarios that describe the controversial issues related to water fluoridation, animal testing, and electromagnetic wave pollution to get informed about the alternative explanations regarding these issues. The other three MEL-diagrams were completed similar to the way climate change MEL-diagram, which was completed as practice. However, the teacher did not provide assistance to the participants for completing the other three MEL-diagrams as he assisted during the completion of the "Climate Change" MEL-diagram. The four MEL diagrams regarding the four socio-scientific issues were given to the participants after they covered "Heat," "Animals' Alimentary Behavior and Digestion," and "Mixtures" units. Each MEL diagram is related to the content covered in either physics, chemistry or biology classes. "Climate Change" and "Electromagnetic Wave Pollution" MEL diagrams were completed after covering the "Heat" unit in physics. In this unit, the participants study the types of heat transfer, including radiation, and prepare projects about pollution. The "Animal Testing" MEL diagram was completed after covering the "Animal's Alimentary Behavior and Digestion" unit in Biology. In this unit, the participants categorize the animals in terms of their food diet, study their alimentary behaviors and, differentiate prey from a predator. "Water Fluoridation" MEL diagram was completed after covering the "Mixtures" unit in chemistry in which the participants studied the types of mixtures and their constituents.

Reflective discussions. Following the evaluation practices and the completion of the first two stages of the MEL diagrams, the participants engaged in 40-50 minutes of reflective discussions about NOS and argumentation concerning alternative explanations of socio-scientific issues. Throughout the reflective discussions, the teacher also guided the participants to identify the three components of Toulmin's argumentation model within each MEL diagram, as well as to recognize the claims, evidence, and counterarguments. Additionally, the teacher guided them to reflect on the tentativeness of scientific knowledge, tentativeness of personal explanations of scientists, validity of information, differences in views, scientific practices, and knowledge construction. Moreover, the reflective discussions targeted the relation of science to social, ethical, political, and economic issues. The participants reflected on the roles of social organizations, associations, and NGOs in certain scientific issues as well. That is, several components of the FRA wheel were addressed during the discussions. For example, the teacher ran the discussion about methodologies, moral and ethical values in animal testing, the political/economic issues related to climate change and, the social issues regarding water fluoridation and electromagnetic wave pollution. A sample of questions for guiding the reflective discussions are provided in Appendix V.

Completion of MEL-diagram questionnaire. After engaging in reflective discussions, the participants were asked to complete the third stage of the MEL-diagrams by responding to the questionnaire and explaining their views of NOS as well as to justify their claims regarding the socio-scientific issues. This questionnaire allowed the participants to further elaborate positions which they support during the reflective discussions, in a written form. Writing after engaging in reflective discussions allows the participants to evaluate their thoughts and make modifications if necessary.

In this way, the participants go beyond writing down their words and express their knowledge more comprehensively as recommended by Chen et al. (2016).

The effects of teaching the participants criteria for evaluating the credibility of information and engaging them in reflective discussions were studied by tracking the changes in the participants' NOS understandings and argumentation skills after the completion of each MEL-diagram. Participants' understandings of social values, scientific ethos, methods, economic issues, and political power structures were also studied through the MEL-diagram questionnaires and interviews.

Data Collection

Data for this study include students' responses to questionnaires entitled Perceptions of Scientific Epistemology (POSE), socio-scientific scenarios for argumentation, and MEL-diagrams. POSE and Argumentation Questionnaire were used as pre- and post-tests to collect information regarding the participants' NOS understandings and argumentation skills before and after the intervention. The MEL-diagram questionnaires were used to collect data about the changes in the participants' NOS understandings and argumentation skills throughout the intervention. Moreover, sources of data included the transcripts of semi-structured interviews and those of the reflective discussions.

Instruments

The following section presents the data collection tools utilized as pre-test and posttest. It also describes the instruments used to collect data regarding the NOS views and the argumentation skills of the participants throughout the research study.

Perceptions of scientific epistemology (POSE) questionnaire. POSE questionnaire includes open-ended questions that assess the participants' views of NOS before and after the intervention. The POSE questionnaire, which includes ten items, is adopted from (Abd-El Khalick, 2002). Out of these ten questions, only six were used because of their relevance to the purposes of this study (see Appendix VI). The content validity of POSE was determined by Abd-El Khalick (2002) in cooperation with expert science educators and researchers. Abd-El Khalick interviewed 45 participants out of the 456 students following the administration of the POSE questionnaire and requested them to explain their responses. He found that the responses of the POSE questionnaire and the interviews are highly consistent.

The open-ended POSE questionnaire is favored because it gives a deeper understanding of the participants' views of NOS and provides the opportunity to explain their points of view. Khishfe and Abd-El Khalick (2002) recommend open-ended questionnaires as a substitute of checklists as they lead individuals to explain and clarify their NOS understandings instead of choosing the opinions already provided in the instrument. Lederman, Wade, and Bell (1998) mistrust the validity of research that relies on multiple-choice or Liker-scale items and suggest qualitative approaches to study individuals' NOS understandings.

Argumentation Questionnaire. The argumentation questionnaire includes a scenario followed by questions for argumentation. This questionnaire was administered before and after the intervention. It is used as a pre- and post-test to study the changes in the quality of the participants' arguments. The scenario is associated with real-life science-related social issues. It presents a controversy that leads individuals to interpret the evidence of the scenarios differently and vote or make personal decisions accordingly. The scenario evokes individuals to make complex argumentation and make good decisions. The questions asked the participants to take a position, make arguments and counterarguments, as well as to represent their views about different NOS aspects. In this research study, the Argument referred to claims and its supporting evidence or reasons. Counterarguments referred to the opposing or alternative explanations of a particular claim.

The scenario that was utilized in this study is the one prepared by Khishfe (2014). Khishfe (2014) used a familiar scenario about Genetically Modified Food (GMF) for grade seven students. This scenario is culturally convenient to the participants because the quality of food in Lebanon has always been a social issue. In cooperation with experts such as science educators, biologists, ethics professors, and high school teachers, the author has assured the content validity of their questionnaire. This questionnaire is presented in Appendix VII. The participants addressed the notion of genetically modified food as they study about the human digestive system and nutrition in the previous unit.

POSE and the argumentation questionnaire, as well as the MEL-diagrams, were piloted with five grade 7 students who did not take part in this study. The purpose of the pilot study was to simulate the administration of the questionnaires to ensure that the questions are appropriate to the participants' age and language proficiency level. The pilot test potentially detected the challenges faced by the participants in responding to the items or solving the MEL-diagrams. The researcher modified or add more details to the instruments upon the results of the pilot test.

MEL-Diagrams. This section presents the structure and parts of the MEL-diagrams. It clarifies the purpose of each part and explains the requirements of the completion MEL-diagrams in detail.

Linking evidence to models. During the intervention, the participants were asked to read the MEL-diagrams, which describe the alternative explanations given regarding the controversial issues and to link evidence to models to show how strongly the evidence supports or contradicts the claim. The arrows drawn by the participants encompass both the epistemic notion of the empirical aspect of scientific knowledge as well as the credibility of the claim based on the quantity and the quality of evidence that supports it. The arrows furnish data about the participants' ability to evaluate the accuracy of claims based on which they had to develop their argument regarding the socio-scientific issue.

Explanatory task. Since drawing arrows gives shallow information about participants' understandings of the "accuracy" criteria of information evaluation and their ability to support a "Claim" with a "Data," their elaboration in the explanatory part provided deeper evidence about their thinking during the completion of the task. Therefore, after each MEL activity, the participants were asked to choose three out of the possible Evidence-Model links that are drawn previously on the MEL diagram. They were required to identify the number of the evidence (i.e., 1, 2. 3…) and the Model (A or B) to which it is linked. Additionally, they were asked to circle the word, or the phrase (i.e., strongly supports, supports, has nothing to do with or contradicts) to show how each evidence is related to the Models. Finally, participants were asked to justify their choices by linking the evidence to the model.

Reflective Discussions

Following the completion of the explanatory task of the MEL-diagrams, the teacher engaged the participants in reflective discussions on NOS and argumentation in the context of socio-scientific issues. These discussions were videotaped and transcribed. The transcriptions were used as another source of data collection. The videotapes are necessary to study the classroom discourse and collect data about students' understandings of the nature of science, as well as to check if they are applying the components of argumentation when discussing controversial social-scientific issues.

Completion of the MEL-Diagram Questionnaire

After the engagement in reflective discussions, the participants were asked to respond to ten questions that target NOS and argumentation. These questions were added by the researcher to study the changes in the participants' views of NOS and argumentation skills throughout the intervention. Appendix III represents a complete MEL-diagram, including the NOS and argumentation questions that are added for this research study particularly.

Interviews

After the administration of the POSE and Argumentation Questionnaire as well as after the competition each MEL-diagram**,** eight participants were selected to participate in semi-structured interviews. The interviewees were selected based on their responses to the pre-tests. After analyzing the pre-test and classifying the participants' understandings of NOS as native, intermediary, and informed, the researcher selected participants from each category to be interviewed and ensured that they represent participants from different levels. The purpose of the interviews was to study the progress of participants' NOS understandings and argumentation development throughout the intervention, as well as to avoid misinterpretations of the quantitative results and clarify and validate the participants' responses to the items of the questionnaire. During the interviews, the students were asked to go over their responses written in the questionnaires, elaborate, and support their answers by providing more examples. Moreover, data regarding Family Resemblance Approach components is collected through the interviews as the participants were asked to clarify their views about the relation of science to social, political, and economic issues that are addressed during the reflective discussions. The interviews were audiotaped and transcribed for further analysis of the participants' responses.

Data Analysis Procedures

The researcher analyzed the data collected from the NOS and argumentation pre- and post-tests, the MEL diagrams, the transcribed interviews following the questionnaires, and the transcribed reflective discussions. Data were coded in accordance with the categories of the analytical framework that was prepared by the researcher (Appendix VIII). The responses of the questionnaires and the interviews of each participant were analyzed and coded separately. A summary of each participants' understanding of NOS and the ability to develop an argument was prepared and documented.

As qualitative research involves the construction of knowledge in certain cultural and social settings, it is more subject to bias compared to the quantitative research (Brod & Tesler, 2009). Therefore, several data analysis procedures are considered to establish confirmability and to ensure that the results of this qualitative research were valid and accurate. First, the dependability of this research study was established by providing a detailed description of the intervention, data collection, and analysis procedures. Moreover, reflective discussions and interviews were recorded and transcribed. During the interviews, the researcher made an effort to follow, instead of a guide, the direction of the interview by asking for clarifications and elaborations. Second, the credibility of the collected data was checked through peer examination. Another science education researcher was asked to participate in the analysis of participants' responses to the questionnaires and to discuss the coding of information. The researcher randomly chose samples of the written responses (POSE, Argumentation Questionnaire, and MEL-Diagram Questionnaire) and coded them together with the other researcher as practice. Later, some of the responses were selected randomly and coded independently by each researcher based on the classifications provided in the FRA analytical framework. The findings of the researchers were compared. The inter-rater reliability was discussed in the results. The researchers had a positive degree of agreement of 82.7% for the responses of the POSE questionnaire and a positive degree of agreement of 88% for the response of the argumentation questionnaire. The researchers discussed the responses discrepancy in their analysis.

Analysis of NOS Views

The responses to the POSE questionnaire were coded and analyzed qualitatively. The students' responses concerning their NOS understandings were classified into three classifications (naïve, intermediary, and informed) based on the FRA analytical framework prepared by the researcher (Appendix VIII).

FRA analysis Framework was developed based on the need for classifying the NOS views of the participants that were associated with the FRA categories. The researcher prepared the framework referring to Erduran & Dagher (2014), and Boujaoudeh et al. (2017)

The analytical framework included the codes of ten themes that were utilized in this research study. These themes were associated with the Cognitive-Epistemic and Social-Institutional aspects of FRA. The themes “Validity of information,” “Tentativeness of scientific knowledge,” “Tentativeness of Personal Explanations in Science,” and “Differences in Views” were subcategorized under the “Aims &Values” category of FRA wheel. The theme “Scientific Practices and Knowledge construction” was subcategories under the Methods, Practices, and Knowledge, as well as Social Certification and Professional Activities categories of the FRA wheel. The “Ethical Issues in Science” theme was subcategorized under the “Scientific Ethos” category of the FRA wheel. The theme “Relationship of Science and Society” theme was subcategorized under the “Social Values” category of the FRA wheel. The theme “Relationship of Science and Politics” theme was subcategorized under the “Political Power Structures” category of the FRA wheel. The theme “Relationship of Science and Economics” theme was subcategorized under the “Financial Systems” category of the FRA wheel. The theme “Relationship of Science and Social Organizations” theme was subcategorized under the “Social Organizations and Interactions” category of the FRA wheel.

Analysis of Argumentation Skills

Through the Argumentation Questionnaire, the participants were asked to take a position, explain the reason for taking a particular position as well as to think of the evidence given by the supporters of the opponents. The quality of the arguments provided by the participants were coded and analyzed qualitatively. The responses were analyzed based on components of argumentation (claim, data, and counterargument). A rubric prepared by Mason and Scirica (2006) was used to evaluate the participants' responses to the scenario about "Genetically Modified Food" (see Table-2). The "rebuttal" section of the rubric is excluded because this argumentation component is not addressed in this study.

Table 2

Categorization of Responses to the Scenario about Genetically Modified Food related to Argumentation Skill

Argumentation component	**No justification or invalid justification**	**Valid justification supported by one reason**	**Valid justification supported by more than one reason**
Argument	Yes (The golden rice should be produced and marketed), I argue for the genetically modified rice because it is the solution.	We need to support the production of genetic rice since it is cheaper to make that than to have a balanced diet for all these people.	I do think than golden rice should be produced and marketed because this rice deals with vitamin A deficiency. Also, scientists believe that eating genetically modified rice can help prevent blindness by improving vitamin A intake during digestion. Preventing blindness can also be caused by two extra genes. This would be very important because childhood blindness affects 500,000 children worldwide each year, which especially happens in developing countries in Asia. Even though the rice might cause contamination to other rice, if it is grown in the same area, there could be new ways to take away the contamination.
Counter-argument	Professor Ponso might think that I am right	Professor Ponso can tell me that there are not enough studies to make sure it is safe.	We do not know how these genetically altered rice can affect us in our health. The rice can also contaminate the other rice.
Rebuttal	I can tell the Professor that he did not convince me.	One thing is that the studies do not show the harm done from this rice.	Instead of genetically modified rice, we can have healthier eating. Moreover, we do not have enough studies that tell us no danger from this rice.

Note. Reprinted from Explicit Nature of Science and Argumentation Instruction in the Context of Socioscientific Issues: An effect on student learning and transfer, by Rola Khishfe. Retrieved from http://dx.doi.org/10.1080/09500693.2013.832004. Copyright 2013 Taylor & Francis.

Analysis of MEL Diagrams

The following section presents the analysis procedures of the MEL-diagrams, in which the participants linked evidence boxes to the Models by several types of arrows. Also, it provides the analytical framework used to analyze the participants' NOS views and argumentation skills and to track their changes throughout the research study.

MEL-Diagrams. Data collected from the MEL diagrams were analyzed qualitatively. The analysis of the types of arrows drawn to link evidence to the models provided data about the participants' ability to evaluate the plausibility of the socio-scientific claims. The researcher classified the arrows drawn as incorrectly linked, correctly linked without elaboration, correctly linked and elaborated with data similar to the evidence provided, and correctly linked, showing a causal relationship between the claim and the evidence. According to these arrows, the participants later developed their argument regarding the addressed socio-scientific issues.

MEL-Diagram Questionnaire. Data about the participants' NOS understandings and their ability to include the three components of argumentation in their arguments were analyzed and sorted by the same NOS and argumentation classifications, as mentioned in Appendix VIII and Table-2. The analysis of the participants' NOS understandings and argumentation skills through their responses to the MEL-questionnaires was performed using the same NOS standards utilized to analyze the POSE questionnaire and similar rubrics as used for analyzing the Genetically Modified Food scenario for argumentation. The analysis of MEL-diagram questionnaires, besides the interviews conducted after each MEL-diagram completion, notably revealed the progress in the participants' NOS understandings and argumentation skills throughout the intervention.

Analysis of Reflective Discussion transcripts

The reflective discussions following the administration of the MEL-diagrams were videotaped, transcribed, and analyzed qualitatively. Additionally, the researcher attended the sessions as an observer to ensure the authenticity of the treatment. The researcher analyzed the reflective discussion transcripts focusing on the participants' declarations regarding their NOS understandings of ten different themes, which included students' views on tentativeness of scientific knowledge and the explanations of scientists, differences in views among the scientists, validity of information, scientific practices for knowledge construction, as well as their perceptions about the social, political, economic and ethical issues related to science. Moreover, the transcripts were analyzed to study if the participants included the components of Toulmin's model of argumentation when debating about the socio-scientific issues.

Analysis of Interview transcripts

The interviews took place after the administration of the pre- and posttests POSE and Argumentation Questionnaire, as well as after each the completion of the MEL-diagram questionnaire to be able to study the progress of participants' NOS understandings and argumentation development throughout the intervention. The researcher transcribed the interviews. Following the administration of each of the questionnaires, eight participants possessing different levels of NOS understanding and argumentation skills were selected and interviewed individually. The participants were asked to read their responses written in the questionnaires, elaborate their answers, and provide more examples to support their positions. Data collection regarding the FRA mainly took place during the interviews, as the participants were asked to elaborate their views on the relation of science with social, political, and economic issues.

In summary, data collected from POSE, argumentation and MEL-diagram questionnaires, as well as the transcription of the interviews and the videotapes were coded and analyzed qualitatively to create profiles for each participant and accordingly answered the two research questions. To answer the first research question, the researcher tracked the changes in the learners' NOS understandings and argumentation skills by comparing their responses to the pre-test and the post-test, as well as their responses to each MEL-diagram questionnaire that was administered after discussing each socio-scientific issue.

To answer the second research question, the researcher compared the profiles of the learners and tried to find a pattern that may show a link between alternative information evaluation and argumentation skills. That is, the researcher investigated if learners who evaluate information credibility more accurately and critically had developed more sophisticated understandings of NOS understandings and more informed arguments. The researcher studied the correlation between participants' argumentation scores and MEL-diagram evaluation scores qualitatively. Moreover, the researcher used SPSS software to find the Pearson correlation between participants' argumentation scores and MEL-diagram evaluation scores quantitatively and rechecked the analysis of the qualitative correlation.

CHAPTER IV

RESULTS

As previously mentioned, the data of this study came from participants' responses to POSE, argumentation questionnaires, and MEL-diagram questionnaires. POSE and argumentation questionnaires were used as pre-and post-tests to collect data regarding the participants' NOS understandings and argumentation skills before and after the intervention. The MEL-diagram questionnaires, which were administered after students were engaging in four sets of activities in four different contexts, were used to collect data about the changes in the participants' NOS understandings and their ability to formulate arguments and counterarguments throughout the intervention. Moreover, sources of data included the transcripts of semi-structured interviews with a number of students and reflective discussions.

The data collected from the questionnaires, reflective discussions, and interviews were used to answer the two research questions. The FRA framework was used as a framework to design the activities and to collect data about students' NOS understandings. The data collected allowed the researcher to study the changes in grade 7 learners' NOS understandings and argumentation skills after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues. Moreover, it allowed studying the relationship between the abilities in alternative information evaluation, NOS understandings, and argumentation skills after engaging in reflective discussions from the perspective of FRA. This chapter presents an overview of the results of this study.

This chapter presents the results of the analysis of the changes in participants' NOS views and argumentation skills after engaging in four sets of activities. The chapter is divided into four main parts: 1) changes in NOS views, 2) changes in argumentation skills, 3) relationship between alternative information evaluation and argumentation skills, and 4) the results of the analysis of NOS views that show returning to former or less developed state of NOS views, which we identified as "Variation" in NOS views, throughout the research study. The first part of the chapter presents the overall analysis of the changes in NOS views regarding ten different themes for the whole class. Then, it provides a detailed analysis of changes in these NOS views of individual participants. The researcher randomly selected three participants and analyzed their responses in detail. The second part of this chapter presents the overall results of the analysis of changes in two argumentation components (formulating arguments and formulating counterarguments) for the whole class, then provides a detailed analysis of these argumentation components of the same three participants who were selected randomly. The third part of this chapter presents the relationship between participants' abilities to evaluate alternative evaluation and their abilities to formulate arguments. The last part of this chapter presents the results of the analysis of NOS views and provides examples of Variation in NOS views of randomly selected individual participants, who show returning to a former or less developed state of NOS views.

First Research Question: How do grade 7 learners' NOS understandings and argumentation skills change after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues?

Part 1: Changes in the NOS Views

At the beginning of the intervention, the teacher explicitly introduced two criteria for evaluating the credibility of information: "Currency" and "Accuracy." Then, he engaged the participants in four sets of activities (Q1, Q2, Q3, and Q4). In each of these sets of activities, he asked the participants to evaluate the credibility of the websites that represented different views regarding four controversial social issues. These controversial social issues in the first (Q1), second (Q2), third (Q3), and fourth (Q4) sets of activities were in the context of climate change, water fluoridation, electromagnetic wave pollution, and animal testing respectively. In each of these contexts, the participants then completed MEL diagrams, which summarized the alternative views and the evidence supporting each opinion regarding the controversial issues, to evaluate the credibility of information and reflect on NOS aspects. Following the evaluation practices and the completion of the MEL diagrams, the participants engaged in reflective discussions on NOS concerning alternative explanations of socio-scientific issues. After participating in reflective discussions, the participants were asked to respond to the MEL-diagram questionnaires and explain their NOS views regarding ten themes. These themes were the tentativeness of scientific knowledge, the tentativeness of personal explanations in science, differences in views in science, the validity of information, scientific practices and knowledge construction, ethical issues in science, the relationship between science and society, politics, economics, and social organizations. The questions of the MEL diagram questionnaires mainly tracked the changes in the participants' understandings of each of the ten NOS themes throughout the research study. Out of sixteen participants, eight participants were interviewed to elaborate their answers further.

Analysis of changes in NOS views for the whole class. The following section presents the analysis of the changes in the participants' views of NOS on the ten themes that were targeted in this research study as a group. The ten themes include tentative scientific knowledge, the tentativeness of personal explanations in science, the validity of information, differences in views in science, the relationship of science with society, politics, economics, social organizations, and ethical issues. The following analysis provides the changes in NOS views on each theme in the pre-test, in the post-test and the four sets of activities (Q1, Q2, Q3, and Q4), which were performed in the contexts of climate change, water fluoridation, electromagnetic wave pollution, and animal testing.

Tentative nature of scientific knowledge. As shown in Table 3, analysis of the responses in the pre-test indicated that, out of sixteen participants, four participants (25%) had naïve views of the tentative nature of scientific knowledge. One participant did not respond to the question that was about the tentative nature of scientific knowledge. Out of the four participants whose views were classified as naïve, a participant considered that scientific knowledge is specific because scientists have approved it. Another participant found that it is hard to change scientific knowledge because they believed that it had been discovered a long time ago. One of the other participants considered that technology is science and technology has spread all over the world, so changing science is not possible, as illustrated in the excerpts below:

> *Scientific knowledge and information on scientific books cannot change because scientists have approved it (P16, pre).*

It [scientific knowledge] will not change because in technology, now, there is science and everywhere right now on planet earth there is science. Science is everywhere, and it will not change (P19[1]; pre[2]).

It [scientific knowledge] will not change because everything that is on earth from 1000s of years ago till now is still the same. So why would it change? (P5, pre)

Table 3

Frequency Distribution and Percentages of Participants' Views of Tentative Nature of Science Themes throughout the Study

FRA Wheel Category	Tentative Nature of Scientific Knowledge Totals (*N=16*)					
	Pre	Q1	Q2	Q3	Q4	Post
Naïve	4 (25%)	1 (6.2 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (%)
Intermediary	9 (56.2%)	8 (50%)	8 (50%)	7 (43 %)	4 (25 %)	6 (37.5%)
Informed	2 (12.5%)	5 (31.2%)	8 (50%)	8 (50%)	8 (50%)	10 (62.5%)

1. Pre: Pre-test, Q1:1st set of activities, Q2: 2nd set of activities. Q3: 3rd set of activities, Q4: 4rt set of activities, Post: Post-test
2. The total number of participants may not be 16 as the participants, who did not respond to the question, were excluded.

Fifty-two percent of the participants had intermediary views of the tentative nature of scientific knowledge on the pre-test (Table 3). They viewed scientific

[1] P: Participant, number following P represents student number
[2] pre: Pre-test

knowledge as subject to change as it might be improved or linked later to newly discovered knowledge in the future as illustrated in the excerpts below:

> *Now, I read that it [Genetically modified food] was good in the text ... maybe they [scientists] still didn't discover that it is bad. Possibly it harms people, but I am not quite sure. We'll see (P2, pre).*

> *Scientific knowledge will change as scientists find more information in the future and make it more advanced (P22, pre).*

Finally, the analysis of the pre-test indicated that only two participants (12.5%) had informed views of the tentative nature of scientific knowledge (Table 3). They considered that specific claims might be improved or might be abandoned and replaced by others. Besides, one of these participants found that scientific knowledge might change as certain environmental factors change with time, as shown in the excerpts below:

> *Scientific knowledge is not entirely accurate. In the future, more intelligent people will find more information, and scientific knowledge will be modified. Scientific products may be improved to have less negative effects (P9, pre).*

> *In the future, the Earth and some natural factors may change. Natural disasters may cause some changes in scientific knowledge. Scientific products such as GMF will be considered healthy food as naturally grown food will be contaminated by natural pollution, global warming, and deforestation. So, our knowledge about GMF will also change as discoveries will be made (P14, pre).*

After engaging in the first set of activities (Q1[3]) in the context of climate change, the number of participants classified as naïve about the tentative nature of scientific knowledge dropped to one (6.2 %). Two participants did not respond to the question. The participant who showed naïve view thought that commonly accepted ideas are impossible to change as can be seen in the excerpt below:

> *Changing scientific knowledge about climate change is impossible because it is common that human activities cause climate change (P18, Q1)*

Moreover, half of the participants (50%) had intermediary views on the tentative nature of scientific knowledge. Most of these participants considered that scientific knowledge changes as scientists provide more detailed evidence regarding an issue through experimentation, as shown in the excerpts below:

> *Maybe they [scientists] discovered something in the past, but now it is developed and changed evidence into something else (P19, Q1)*

One of the participants was aware of how scientists control variables and study the effect of other variables, as seen in the excerpts below:

> *If the pollution of human activities decreases and the solar system stayed as it is like the solar system effects of climate change will increase …we say that if it is from the solar system (P16, Q1)*

However, after engaging in Q1, more participants (31.2 %) showed informed views of the tentative nature of scientific knowledge (Table 3). More students claimed that scientific knowledge changes over time but the reasons why this happens were

[3] Q: set of activities, number following Q represents the order of the set of the activities

related to collecting more evidence, as well as to getting convinced by alternative explanations as shown in the excerpts below:

People may support model A, but people from model B tell them facts and evidence that support model B. Maybe they change their minds about it (P14, Q1).

If something is happening and there was evidence, data and research then scientists would probably change, but no-till now we don't have so they don't change their opinion (P5, Q1)

Scientific knowledge may change because it might be debunked, or scientists may find out which opinion is more probable (P9, Q1).

After engaging in the second set of activities (Q2) in the context of water fluoridation, none of the participants showed naïve views of the tentative nature of scientific knowledge (Table 3). Half of the participants showed intermediary views, which consider that change in scientific information, is limited to "discovering" new information that might disprove the old data and change the minds of scientists as illustrated in the excerpts below:

For example, Pluto used to be a planet, but now it is not (P11, Q2).

A scientist may discover something new or may find out that something they discovered before was wrong (P10, Q2).

One of the participants having an intermediary view mentioned that scientific knowledge changes because people change in the society, as shown in the excerpt below:

Scientific information may change with time because the people in society keep on changing (P10, Q2).

The other half showed informed views of tentativeness the nature of scientific knowledge, considering that scientists make adjustments in scientific data and give new recommendations based on new evidence (Table 3) as shown in the excerpts below:

Because of evidence number 1, they decreased the amount of fluoride in water because they discovered from a long time ago in 1975. Then, they found that it is not good in 2015 (P2, Q2).

The new recommendation about fluorine changed because the discoveries and researches (P19, Q2).

Several participants thought that the current and newly found evidence might disprove the proof provided by experiments that were performed earlier. In addition, others considered that, nowadays, scientific knowledge is more subject to change because scientists have the chance to share information through the internet and give a more detailed explanation about the advantages and disadvantages of fluoridation as shown in the excerpts below:

Like in the past, the amount of fluorine was very high in the water, and then they discovered that we should not put that much amount of fluorine in water because it causes many negative effects like lowering the IQ and problems in nerves so in 2015 they decreased its amount. This high amount of fluorine is not good for us anymore (P14, Q2).

Maybe in the future, they will have more equipment to do the studies with, and they may have a solution about which is the right one (P9, Q2).

Some people, when they did experiments before that said it, [water fluoridation] is good, but more lately, they said it is not good, so scientists should be following the one that is more current, not the one that is a long time ago. Maybe a long time ago they thought that water fluoridation is something really good. Over the years, when they do more research and put new stuff on the internet, it might add more information, and it will tell why it is good and why it is bad, [more detailed explanation] and maybe find out that it has a bad effect (P22, Q2)

These different views did not seem to change much over time. After engaging in the third set of activities (Q3) in the contexts of electromagnetic wave pollution, one participant did not respond to the question about the tentative nature of scientific knowledge. One of the participants showed naïve views (0%) (Table 3). Seven participants (43%) showed intermediary views of the tentative nature of scientific knowledge. These participants claimed that scientific knowledge might change based on new evidence. Few participants mentioned that advancements in technology help reduce the harmful effects of electromagnetic waves and change scientists' views regarding electromagnetic wave pollution, as shown in the excerpts below:

Yes, if further researches were made (P18, Q3)

Yes, because after all, they're [scientists] giving much evidence and information (P12, Q3)

Yes, because later I just might come up with electronic that do not have electromagnetic waves (P20, Q3)

Fifty percent of the participants (8 students) came up with informed views of the tentative nature of scientific knowledge (Table 3). The participants mentioned more than one idea regarding reasons for making changes in scientific knowledge. These ideas included discoveries that lead to new evidence that may support or disprove the already existing data, and changing social factors like more dependence of people on electronics, as shown in the excerpts below:

> *Yes, because we might find out more about it. Maybe like I don't know after also ten years, everyone will start having cancer. Or the number of people now and the number of electronics are evolving, and new devices are coming out. So everyone is starting buying even more (P2, Q3)*

> *Scientists' thoughts, conceptions, and opinions may change based on different evidence, and the proof resulted from further research studies in the future (P4, Q3)*

> *If our technologies are advanced in the future and if we go deeper into objects, then we would probably change. But for example, the gravity will not change in the future because from thousands of years it is the same and there are major things that we keep the same but minor things we may change it if we advance the technology (P5, Q3)*

After engaging in the fourth set of activities (Q4), in the context of animal testing, none of the participants showed naïve views regarding the tentative nature of scientific knowledge (Table 3). Three participants did not respond to the question. Four participants (25%) had intermediary views regarding the tentative nature of scientific knowledge. One of the participants mentioned that changes in scientific knowledge might be due to changes in human activities and the ecosystem. Another participant thought that scientific knowledge changes as data that are more detailed and tangible evidence are provided, as shown in the excerpts below:

Maybe because the Earth can change in the future because of human activity (P5, Q4)

Yes, if they give me more data and visual evidence (P12, Q4)

Yes, if more data and researches were made (P18, Q4)

Half of the participants (50 %, eight students) showed informed views by providing more than one idea regarding the tentative nature of scientific knowledge. They suggested that advancements in the currently existing technologies allow scientists to identify more accurate information, collect more evidence, and replace animal testing procedures with more appropriate methods thus leading to changes in scientific knowledge as shown in the excerpts below:

Scientific knowledge changes as discoveries are made with advanced technology, and more exact/accurate evidence becomes available. With advanced technology methods of researching will change, and it will replace animal testing (P22, Q-4)

Yes. They will like to change their opinion because that in the future of the technology will evolve and it will be more advanced so scientists will use technology to test on and not on animals or humans. So definitely some scientists will change their opinion (P8, Q4)

Analysis of the responses in the post-test indicated that none (0%) of the participants had naïve views of the tentative nature of scientific knowledge (Table 3). Moreover, 37% of the participants had intermediary views of the tentative nature of scientific knowledge on the post-test (Table 3). They viewed that discoveries about the negative and positive effects of certain scientific products may cause changes or improvements in scientific knowledge, as shown in the excerpts below:

> *The scientific knowledge found in my science books might change in the future because every discovery information might change (P15, post[4]).*

> *Yes because nowadays everything is getting more advanced and new discoveries and more experimenting can be made (P12, post)*

The number of the participants showing informed views of the tentative nature of the scientific knowledge increased to 62% in the post-test (Table 3), indicating that the majority of the participants were able to develop informed views about the tentativeness at the end of the research study. Some of these participants showed awareness that not all scientific knowledge is subject to change. However, most of the participants thought that scientific knowledge changes as advanced technology and equipment allow scientists to discover and add more detailed information to the currently accepted knowledge. They thought that as more details are found, scientific knowledge is updated as seen in the excerpts below:

> *Maybe not all of them [scientific knowledge]. Like there are facts in science that are supposed to be right. But different things might change because we are discovering more in the future and the world is getting advance so they might*

[4] post: Post-test

discover new things and technology is getting advanced, and you can do anything with it so I guess we can always discover more. (P2, post)

Yes, it may change because they may read and see more. Of course, it will change because scientists retest their facts and upgraded (P16, post)

Yeah, not everything because some things can't change. For example, the density of water can't change, but for example, when Pluto was once considered as a planet but now they changed, and they think that it is not a planet. So, if we look in the old textbooks, we can see that it is the still a planet, but we should look at the more current ones because we can see current information and accurate because it is more current (P22, post)

The tentativeness of personal explanations in science. As shown in Table 4, analysis of the responses of the pre-test indicated that none of the participants had informed views of the tentativeness of personal explanations in science (Table 4). However, seven participants (43 %) had naïve views. Out of these seven participants, two did not respond to the question about the tentativeness of personal explanations. One of the participants considered that it is impossible to change his explanations or decisions, even if more information is provided about GMF. Another participant believed that changing positions regarding an issue is a personal matter that depends on how indecisive an individual may be as shown in the excerpts below:

I would like to know more about this issue [GMF], but it will not change my decision (P11; pre).

Changing positions regarding an issue depends on how fast a person regularly and easily changes his/her mind (P15, pre

Table 4

Frequency Distribution and Percentages of Students' Views of Tentativeness of Personal Explanations in Science Themes throughout the Study

FRA Wheel Category	The tentativeness of Personal Explanations in Science Totals (*N=16*)					
	Pre	Q1	Q2	Q3	Q4	Post
Naïve	7 (43 %)	0 (0%)	0 (0%)	1 (6.2 %)	0 (0%)	0 (0%)
Intermediary	7 (43 %)	11 (68.7 %)	8 (50%)	9 (56.2%)	7 (43 %)	10 (62.5%)
Informed	0 (0 %)	5 (31.2%)	8 (50%)	5 (31.2%)	6(37.5%)	6 (37.5%)

1. Pre: Pre-test, Q1:1st set of activities, Q2: 2nd set of activities. Q3: 3rd set of activities, Q4: 4rt set of activities, Post: Post-test
2. The total number of participants may not be 16 as the participants, who did not respond to the question, were excluded.

Others have thought that it is impossible to change opinions regarding the production of GMFs because people are sure about the benefits of GMF as illustrated in the excerpts below:

> *Changing positions regarding GMF is not possible because it has many advantages (P16, pre).*
>
> *Changing position regarding the production of GMF is not possible when people are sure that GMF is benefiting people (P19, pre)*

Forty-three percent of the participants had intermediary views of the tentativeness of personal explanations and opinions on the pre-test (Table 4). These participants thought that people might change their opinions about the production of the GMF when scientists find negative or positive effects of GMFs. Other participants mentioned that people change their positions when scientists provide better alternatives for GMFs. Finally, one participant claimed that positions regarding the manufacture of scientific products might change because these products could be manufactured differently in the future, as illustrated in the excerpts below:

> *People change their opinions about a scientific product like GMF when these products cause harm or even death (P18, pre).*

> *People change their positions because, in the future, scientists might provide better solutions and inventions (P14, pre).*

> *I might change my decision in the future if it [GMF] does a lot of negative damage more than positive or if it is just not good enough anymore because they started to make it differently … better in a positive way or worse in a negative way. I might change my mind (P9, pre).*

After engaging in the first set of activities (Q1) in the context of climate change, the number of participants classified as naïve about the tentativeness of personal explanations sharply dropped from 56.2% to 0% (Table 4). Besides, more participants (68.7 %) showed intermediary views of the tentativeness of personal explanations (Table 4). These participants considered that people change their minds when evidence and data about alternative opinions are provided through discoveries, as shown in the excerpts below:

If there wasn't enough data [that disprove their opinion], then why would they change their minds? (P5, Q1)

People change their decisions regarding a certain issue based on what starts to make more sense to them (P10, Q1)

Scientists and people change their minds when the available information changes (P11, Q1).

At the end of Q1, the number of participants having informed views increased to 31.2% (Table 4). Participants thought that scientists keep on conducting research studies and discovering new information and stronger evidence about a particular issue. Therefore, their new experiences may result in different conclusions and lead people to question their explanations, as described in the excerpts below:

Different conclusions may be reached out creating doubts in people's mind and changes in their opinions (P9, Q1)

Scientists continue experimenting and calculating non-stop, which makes them find out new information to support their opinions. This will help them end up with one opinion which will be better for everyone (P8, Q1)

Scientists find out stronger evidence and have new experiences that may change their mind (P4, Q1).

After engaging in the second set of activities (Q2) in the context of water fluoridation, the number of the participants having naïve views of the tentativeness of personal experiences remained zero (0%) (Table 4). Half of the participants showed intermediary views which suggest that changes in personal explanations are limited to discovering more information about the positive or negative effects of water fluoridation that may disprove or support a certain claim more than the other as illustrated in the excerpts below:

> *Changing position and views regarding a certain issue may take place when more information is discovered about the claim or the opposing claim (P2, Q2)*
>
> *Changing position regarding the fluoridation of water is possible if the negative effects of water fluoridation are known (P4, Q2)*
>
> *If the claim which a person is supporting is proven wrong, that person may change his or her viewpoint (P21, Q2)*

The other half (50%) showed informed views of the tentativeness of personal explanations (Table 4). These participants consider that individuals might change their positions regarding a certain issue as others discover stronger evidence to support their claim and succeed to convince them through argumentation, as shown in the following excerpts:

> *Changing positions regarding a scientific issue like fluoridation are possible when the scientists who support the opposing claim provide more convincing evidence (P22, Q2)*
>
> *Scientists may start supporting the alternative claim if more convincing evidence becomes available (P9, Q2)*
>
> *I will probably not change. If they had convincing and strong evidence on model B let's say evidence I might change (P5, Q2)*

Scientific knowledge may change as scientists perform more research with time and find more convincing evidence. Scientific knowledge changes as scientists argue over the available evidence, change their point of views and agree on another point of view P4, Q2)

In the answers to the third set of activities (Q3), one participant did not respond to the question about the tentativeness of personal explanations. One participant (6.2 %) showed naïve views. (Table 4). This participant considered changing positions is impossible because scientists find claims to be logical and convincing, as shown in the excerpt below:

Changing position regarding an issue is not possible when the claim seems logical while the alternative claim shows negative consequences (P15, Q3)

After the completion of Q3, nearly half of the participants (56.2%) showed intermediary views on the tentativeness of personal explanations (Table 4). These participants considered that individuals change their minds and that science changes over time. However, the reason why these changes occur was related to acquiring new knowledge about the negative and positive effects of the scientific products and proving which claim is right, as shown in the excerpts below:

Yes, I might change my position if in the future scientists discover that electromagnetic waves cause cancer *(P14, Q3)*

Yes because maybe in the future more people get infected by cancer (P9, Q3)

I may change my position regarding the issue when scientists prove and give more evidence for model B then I may change my position (P11, Q3)

Other participants thought that the availability of more advanced technologies in the future would allow scientists to utilize more sophisticated equipment and methods of experimenting. Scientific practices may change in the future and lead to minor changes in some of the scientific knowledge and individuals' opinions as well. These participants also thought that people change their minds when technological advancements reduce the negative effects of scientific products, as seen in the excerpts below:

Yes because later I just might come up with electronic that do not have electromagnetic waves (P20, Q3)

Maybe there are different materials they use the technology nowadays is very advanced from the past (P9 Q3)

In the answers to the questions at the end of the third set of activities (Q3) in the contexts of electromagnetic wave pollution, the number of participants showing informed views of the tentativeness of personal explanations was 31.2 % (Table 4). These participants considered that people change their opinions when scientists use advanced technology to come up with evidence that is more detailed and current. The new evidence may lead to changes in the currently available scientific knowledge. The changes in evidence and scientific knowledge might lead to changes in decisions people make, as shown in the excerpts below:

It depends on the evidence. I don't think I will change my point of view. But if evidence for model B becomes stronger and more current, I would support model B. Also, in evidence number 8 it says that looking at trends over the last 20 30 years we don't see an increase in cancer, but they don't know if it takes *cancer ten years to promote. So maybe after ten years if the cancer was not promoting and they had a proof for it then I might support model B (P22, Q3)*

Based on different evidence and the proof result from research can change according to the scientists' thinking. In Evidence 2, they said that in 1989 electromagnetic waves cause cancer. This evidence may be continued, or else they change their mind about this issue (P4, Q3)

Few participants mentioned that scientists might change their position because the way scientists think may change with time, as shown in the excerpts below:

Scientific logic may change as time passes, so we need to chat more than one article and to check the date of when it was written (P9, Q3)

People change their opinions because of the way scientists think and analyze may change with time (P10, Q3)

After engaging in the fourth set of activities (Q4) in the context of animal testing, none of the participants showed naïve views of the tentativeness of personal explanations (Table 4). Two participants did not respond to the questions. Seven participants (43%) had intermediary views of the tentativeness of personal explanations. These participants considered that individuals change their minds regarding animal testing when certain evidence or experimental conditions change. Several participants mentioned that changing positions is only possible when the claims do not oppose personal values and principles.as shown in the excerpts below:

Yes maybe I could change my opinion from model B to model A if scientists tested animals who don't give us food (P21, Q4)

No, I don't think I'll change my position regarding this issue because I think harming animals is immoral (P11, Q4)

Maybe it depends on the more correct evidence. But I don't think I will change because for me it is not ok to test on animals, so I don't think I will change my mind (P22, Q4)

At the end of the fourth set of activities (Q4), six participants (37.5%) showed informed views of the tentativeness of personal explanations. These participants considered that people change their opinions when scientists come up with evidence that is more detailed and current that may lead to changes in the currently available scientific knowledge. The change in evidence may lead to a change in decisions people make, as shown in the excerpts below:

Yes, they will definitely like to change their opinion because, in the future, the technology will evolve, and it will be more advanced. So, scientists will use technology to test on and not on animals or humans. So, definitely some scientists will change their opinion (P2, Q4)

Different evidence convinces someone. Maybe someone is persuasive and leads to change his mind by providing facts and something like that I got convinced by my classmates that it is more ethical to support Model B and there is no reason to do animal testing using model A and what is even the point if you can use model B (P9, Q4)

Technology may replace animal testing, and people may have a more advanced machine to test that old and not on animals. They may make robots and test on them. Scientists might change their idea about something since maybe in the *future the scientists will stop or continue harming the animals so we might shift from one model to another. As my friend was first ok with harming the animals, he didn't mind that, and at the end, after discussing it at class, he was convinced that you should support model B since it is not our right to harm the animals (P14, Q4)*

Several participants considered that changing positions regarding an issue occurs when people share their ideas and evidence, and succeed to convince others with their point of view. The participants experienced this as during the reflective discussions on animal testing, as P9 changed his position regarding performing tests on animals after he got convinced by the evidence given by his classmates. The views of these participants are illustrated in the excerpts below:

I got convinced by my classmates that it is more ethical to support Model B, and there is no reason to do animal testing using model A and what is even the point if you can use model B. It is much better since you are not harming. You are just taking samples of cells. You can do that for multiple animals. Maybe a gorilla has different than the chicken or something. You can take more DNA and cells and check without harming anybody… different evidence that convinces someone … maybe someone is persuasive and leads to change his mind by providing facts and something like that (P9, Q4)

[During the discussion, P9 changed his decision] because maybe he has seen that how the other people's opinion are convincing to him and that is correct that model B is more supportive than model A… maybe he has seen that his opinion turn out to be wrong or he is thinking … He didn't think Wisely before

answering model A or model B. He thought that model B is better than Model A like my friends that are telling that is a better solution. Like the technology or trying to use it in a good way… scientists can really make sure that animal testing is 100% going to their answer. Like it is going to be for sure. I don't know. Things in the digestive system to change all the DNA they should test and be 100% sure that this will happen before using it on animals… it will harm like the whole animal. (P8, Q4)

Analysis of the post-test showed that none of the participants had naïve views of the tentativeness of personal explanations (Table 4). The ten participants (62.5%), who had intermediary views, also referred changes in personal explanations to changes in evidence about the negative and positive effects of scientific products as indicated in the excerpts below:

It depends if golden rice turned out to be good or if it has any negative side effects maybe I might change (P2, post)

Yes, because with time. As I said, golden rice may not prevent that much of blind people, and it will have more side effects on people. (P4, post)

Yes if they tell us that if you take a large amount of golden rice, it might cause cancer (P12, post)

Scientists and people always change their minds because new factors are being learned, maybe people who had a certain disease are allergic to this. The certain things that they put in the genetically modified food. So it might not be good for everybody. They might have to change some stuff. They might change their minds about genetically modified food. You leave the idea and try to start *something else. People who are against genetically modified food might try to do experiments and find more negative effects, and if there are more negative effects, maybe they might change the positive side of it. Maybe they say that genetically modified food is good (P9, post).*

The justifications that participants who held intermediary views gave in their responses to the open-ended questions show that most of them believed that there was absolute truth and the scientists are trying to find out that truth, as shown in the excerpt below:

Yes, maybe in the future, scientists may discover or invent more ways better than genetically modified food. If in the future, the scientists said that and proved 100% that it is not good for the plants all for our body, I might change my opinion about genetically modified food (P14, post).

Likewise, analysis of the post-test showed that six participants (37%) had informed views of the tentativeness of personal explanations (Table 4). These participants gave more than one informed view regarding changes in personal explanations. Many participants considered that changing positions regarding an issue occurs as well when individuals share their ideas through discussions or compare the information of different articles when they try to convince others by providing evidence that supports the opposing claim and when they engage in argumentation. The participants thought that people might change their positions depending on the availability of stronger and more convincing evidence. In addition, positions change depending on how people convince others with their opinions. The informed views of these participants are illustrated in the excerpts below:

According to scientific knowledge, anything could happen with this issue. So if in the future, we discover that genetically modified rice is not good to sell, I will most likely change my mind. When there is research being done to show me that the evidence about the research they have done is strong enough to convince me like it can cause side effects on people (P5, post)

They can change their opinion because for example one of my classmates when we were talking about the animal testing, in the beginning, he was supporting model A which said that it was ok [to do animal testing] and after he listened to the opinions of his friends he realized that it wasn't ok and he changed his mind, so it depends on other people's opinions and how do you get influenced by those opinions and how do they affect you because you understand more about the topic if you understand more about the different points of views so you will be able to make a decision (P22, post)

Yes, I will change my decision because when I see that there are more articles to be convinced with, I will be convinced and I will change my opinion. I am not convinced that GMF is good for the body. Maybe later, I will be convinced more if genetically modified food is not good for the body. After I compare articles and I get information about the genetically modified food that it is not good and how it affects the body (P16, post)

Scientists might change their idea about something since maybe in the future the scientists will discover what mainly causes the animals and we will stop or continue harming the animals so we might shift from one model to another. And as my friend was first ok with harming the animals, you didn't mind that, and in *the end, after discussing it in class, he was convinced that you should support model B since it is not our right to harm the animals. Technology may replace animal testing, and people may have a more advanced machine to test that old and not on animals. They may make robust and test on the. (P14, post)*

Validity of information. Analysis of the responses of the pre-test that assessed students' understanding of the validity of information indicated that none of the participants had naïve or informed views of the validity of information (Table 5). Five participants did not respond to the question. The rest of the participants (75 %) had intermediary views about the validity of information on the pre-test (Table 5). These participants realized the importance of evidence for supporting a certain explanation and supporting claims. They considered that knowing more about a certain claim is necessary to ensure the validity of information used and to make more informed decisions, as shown in the following excerpts:

Evidence regarding the negative effects of the GMF is required (p4, pre)

I want the scientists to go into the interknit discoveries to know if the genetically modified food is good for us (P9, pre)

More information is required regarding the effects of genetically modified food (P22, pre)

After engaging in the first set of activities (Q1) in the context of climate change, none of the participants had naïve views of the validity of the information. Three participants did not respond to the question. On the other hand, out of sixteen participants, 50 % showed intermediary views of the validity of information (Table 5). Several participants recognized the importance of checking multiple resources for ensuring the validity of the information and try to find commonalities. Moreover, few participants mentioned the necessity of finding current evidence to make sure that the data is current and accurate, as shown in the excerpts below:

> *I want to say that they need to check other websites so that they see if there is something in common, as he said, and they find something that has nothing to do with the topic than it is wrong. (P2, Q1*)

> *It [checking multiple resources] is important to see the common information between them to say whether it is true or not. (P12, Q1)*

> *Evidence has to be current (P5, Q1)*

Table 5

Frequency Distribution and Percentages of Students' Views of Validity of Information in Science Themes throughout the Study

FRA Wheel Category	Validity of Information Totals (*N=16*)					
	Pre	Q1	Q2	Q3	Q4	Post
Naïve	(0 %)	0 (0 %)	(0 %)	0 (0 %)	0 (0 %)	0 (0%)
Intermediary	12 (75 %)	8 (50%)	4 (25 %)	6 (37.5%)	5 (31.2%)	12 (75%)
Informed	0 (0 %)	5 (31.2%)	9 (56.2%)	8 (50%)	8 (50%)	4 (25%)

1. Pre: Pre-test, Q1:1st set of activities, Q2: 2nd set of activities. Q3: 3rd set of activities, Q4: 4rt set of activities, Post: Post-test
2. The total number of participants may not be 16 as the participants, who did not respond to the question, were excluded.

Besides the importance of the supporting evidence, one participant considered that data become more valid and probably right when it is supported by a larger number of people, as seen in the following excerpts:

> *Model A because it is the more talked about, so it is more probable. More people are believing in model A than in model B because there might be more evidence and data, and it is more believable or probable like the changes in the solar system are not probable because it didn't happen before like the greenhouse gases because of a long time of using them this is what happens but something with the solar system maybe it should have happened before. (P9, Q1)*

Another participant mentioned the importance of analyzing the credibility of the evidence that is provided to support a certain claim, as shown in the excerpts below:

> *Evidence provided is not enough to make changes in the decision. Reasons to trust those evidence is also required (P8, Q1)*

At the end of the first set of activities (Q1) in the context of water fluoridation, the number of participants having informed views increased to 31.2% (Table 5).

Participants having informed views mentioned more than one idea regarding the validity of the information. These participants highlighted the importance of having robust and current evidence supporting the data. Few participants mentioned the importance of checking what alternative perspectives think about an issue to ensure their validity, as shown in the excerpts below:

> *One of the human activities firstly because the evidence strongly supports the model like the other one was not very strong the evidence. Also, it is more*

current everybody knows that human activities are releasing lots of gases, so that's why [for solar system] there is no evidence… There is no strong evidence. No evidence is exactly clear (P22, Q1)

It is better to read about different points of view to check the validity of the information. The most updated information of all is preferable (P15, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, three participants did not answer the question. Moreover, none of the participants' views were classified as naïve. Four of the participants (25 %), who showed intermediary views claimed that validation of information is limited to finding more information and making more evidence available, as illustrated in the excerpts below:

The more evidence/information supports a certain claim, the more valid it becomes (P2, Q2)

Claims are more valid when they are supported by more specific and detailed evidence (P10, Q2)

The participants showing informed views of the validity of information increased from 31.2 % to 56.2 % after engaging in the second set of activities (Q2) (Table 5). These participants considered that information becomes more valid as scientists repeat their experiments and end up with similar results. These participants focused on both strength and quantity of evidence supporting the validity of information, as well as on its currency and accuracy, as shown in the following excerpts:

Information becomes more valid when tests are repeated, and similar results are concluded. In this case, the data is considered to be a trustful fact that is proven and supported by data (P4, Q2)

What makes a data valid is the amount of evidence you have and how strong it supports the model (P5, Q2)

When we check the year, we know when this data was discovered, and when we check other resources, they check if another discovery is covering the topic, and if we check the author or who wrote it, we can see if he is actually related to this article or not. (P19, Q2)

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, two participants did not respond to the questions, and none of the participants had naïve views of the validity of the information. Six participants (37.5%) showed intermediary views. Some of these participants thought that the validity of information is confirmed by conducting many research studies that produce extraordinary and convincing evidence based on common sense.

What makes a data valid is common sense and a lot of studies (P2, Q3)

I think that model B is more supported than model A because all evidence that is supporting model A are a common supportive idea that isn't really convincing (P8, Q3)

They gave a lot of examples and experiment and evidence (P20, Q3)

After engaging in the third set of activities (Q3) in the above context. Half of the participants came up with informed views (Table 5). These participants elaborated on the necessity of checking multiple resources and supporting claims with a greater number of current and accurate evidence to ensure the validity of the information. They claimed that information is considered valid when it is supported by recently discovered and irrefutable evidence. They also stated that checking multiple resources is important for validating information because it allows finding the commonalities among the resources, as shown in the excerpts below:

> *The currency and the accuracy of data and evidence. Like the articles published in 1920 might have different information than those published this year because more discoveries are being discovered every day. [It is necessary to check] multiple resources to see the common information between the articles and that will be the fact that scientists have discovered (P14, Q3)*

> *Model B, because it has more proofs, and it convinced me more. They based on 25000 articles. 25000 articles prove that model B is better than model A so, of course, I will support model B (P16, Q3)*

> *Checking multiple and more recent resources increases the chance of finding more valid data because the way scientists think may change with time (P9, Q3)*

> *Because the currency may tell you whether there is a new discovery or not like if scientists did new articles about the new discoveries [checking multiple resources increases validity] because if we find a lot of articles that contain the same common thing that they are talking about it (P19, Q3)*

After engaging in the fourth set of activities (Q4) in the context of animal testing, two participants did not respond to the question about the validity of information, and none of the participants had naïve views. Five participants (31.2%)

were classified as having intermediary views. Many of these participants thought that the validity of information depends on the availability of convincing evidence resulting from research studies. Many participants mentioned that convincing data help people make informed decisions about a certain issue. Some were aware that not every claim given by scientists is right. Scientists may give opinions as seen in the following excerpts:

What makes a data valid is when you find it more convincing evidence and research, and they found what is the most convincing to them, but it doesn't really need to be right. It will be their opinion on it. (P8, Q4)

The provided data is valid enough for me to take a position regarding animal testing because there is enough evidence for me to take a decision (P15, Q4)

Yes there has to be enough data to take a position regarding the animal testing (P12, Q4)

Fifty-percent of the participants showed informed views of the validity of information after engaging in the fourth set of activities in the context of animal testing. One of the participants mentioned that the validity of information might depend on the use of technology during experiments, as seen in the excerpt below:

Technology helps scientists collect more accurate and trustful data (P9, Q4)

I support model B because it has more evidence that supported it and convince me to support it [important to check current information] in the past there were discoveries made, but now technology is getting more advanced… (P19, Q4)

Several participants claimed that the currency, accuracy, and strength of evidence ensure the validity of information, as shown in the excerpts below:

> *The accuracy, currency, and how exact the info are the things that make data valid. Also, some models are more commonly supported (P22, Q4)*

> *Currency is very important to check all the articles because in the past or from the past until now more scientific researches and developments or every day. For example, as P-22 said their discoveries didn't know the dangers of the chemicals, they were putting in the animals (P14, Q4)*

> *During the discussions, there was a lot of discussions a lot of people change their minds to have first of course how strong is the evidence and second the currency of the articles how they support the model. (P5, Q4)*

Analysis of the post-test showed that none of the participants showed naïve views of the validity of knowledge (Table 5). However, more participants showed intermediary views in the post-test (75 %) compared to the previous questionnaires that were conducted at the end of the third (37.5 %) and the fourth (31.2 %) sets of activities. The views of these participants suggested that the validity of information is limited to supporting a claim with evidence. Few participants mentioned the importance of evidence for validating data and making decisions regarding an issue, as shown in the excerpts below:

> *[The information is valid] because the information available is enough to make decisions (P16, post)*

> *No, the information is not enough to make a decision because better they give us as enough evidence information research and facts (P20, post)*

Yes, more evidence is needed [to take decision]. More positive effects should be given about GMF. Positive effects, for example, if the people who were prevented by the rice reached 1 million in the world or if it can prevent other vitamin deficiencies. (P5, post)

A lower percentage of participants demonstrated informed views in the post-test (25 %) compared to the previous questionnaires that were conducted at the end of the third (50%) and the fourth (50 %) sets of activities (Table 5). The participants having informed views focused on the amount of irrefutable evidence, as well as on the importance of comparing different information from different resources to ensure the validity of information as shown in the excerpts below:

To read more articles about what people and scientists think and compare their experience and my experience. I can compare them and see how scientific knowledge is structured and built compared to mine, and it really convinces me, and I will change (P5, post)

[To check the validity of information], I would like to have more accuracy in the information. And the website to know and get more information about it and compare the negative and the positive effects (P14, post)

Differences in views among scientists. As shown in Table 6, analysis of the responses in the pre-test indicated that, out of sixteen participants, six participants (37.5 %) had naïve views of differences in the views of different scientists or individuals. These participants found surprising that different scientists disagree and develop different points of view regarding a specific issue, as shown in the excerpts below:

It is surprising that scientists disagree because they know everything (P21, pre)

The disagreement among scientists is surprising because others should trust what scientists have approved (P18, pre)

Table 6

Frequency Distribution and Percentages of Participants' Views of Differences in Views in Science Themes throughout the Study

FRA Wheel Category	Differences in Views in Science Totals (*N=16*)					
	Pre	Q1	Q2	Q3	Q4	Post
Naïve	6 (37.5 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (%)
Intermediary	8 (50 %)	9 (56.2 %)	3 (18.7 %)	2 (12.5 %)	3 (18.7 %)	2 (12.5 %)
Informed	2 (12.5 %)	6 (37.5%)	12 (75 %)	12 (75 %)	12 (75 %)	14 (87.5%)

1. Pre: Pre-test, Q1:1st set of activities, Q2: 2nd set of activities. Q3: 3rd set of activities, Q4: 4rt set of activities, Post: Post-test
2. The total number of participants may not be 16 as the participants, who did not respond to the question, were excluded

Half of the participants (50 %) had intermediary views on the reasons for disagreements among the scientists (Table 6). They considered that scientists have different opinions regarding specific issues because they have different background information to which they refer when thinking about the issue. Moreover, few participants were aware that scientists might have different opinions that may be possible to change upon falsification, as illustrated in the excerpts below:

They [scientists] might have discovered something others scientists didn't discover (P2, pre)

It is not surprising that scientists disagree because everyone has his own opinion (P9, pre)

Scientists have different points of views which may be changed when they discover that they were wrong (P14, pre

Finally, the analysis of the pre-test indicated that only one participant (6.2%) had informed views of differences in the views of different scientists (Table 6). These participants were aware that scientists might think and analyze data differently depending on their points of view, as shown in the excerpt below:

It is not surprising that scientists disagree because every scientist looks at the information from a different perspective, so they think of it in their own way (P22, pre)

After engaging in the first set of activities (Q1) in the context of climate change, the number of participants classified as naïve about the differences in the views of scientists dropped to zero (0 %) (Table 6) while one participant did not respond to the questionnaire.

At the end of the first set of activities (Q1), nine participants (56.2 %) showed intermediary views (Table 6). These views suggested that either difference in views among scientists are limited to collecting different data or having different experiences, which allow them to develop different perspectives as illustrated in the excerpts:

Scientists support different views based on their personal life experiences (P12, Q1)

If scientists collect different data about a certain issue, then every scientist would support a different point of view (P15, Q1)

Scientists have a different view and think differently because of the support of evidence for each data. Some may need more evidence to make decisions (P19, Q1)

However, after engaging in Q1, more participants (37.5 %) showed informed views on differences in views of scientists (Table 6). Students claimed that the differences in views result from having different mind-sets and methods of analyzing the data. A few of them mentioned that differences in observations and experiences also might result in different points of view, as shown in the excerpts below:

Scientists disagree because of differences in evidence and data, as well as different mind-set and logic (P9, Q1)

People who support different issues have seen and experienced different things in life (P18, Q1)

Many participants recognized that sometimes the position of the individuals depend on their benefits, as shown in the excerpts below:

Scientists have different views because they think about and make sense of the same data differently based on the evidence they prove from the right hypothesis. Moreover, their benefits lead them to support the position that won't affect their benefits (P14, Q1)

Also, some scientists might support the solar system ideas because they don't want to support [The model that targets] the greenhouse gases since the gases *come from factories and staff that make the gases. Some people work there so if they support that they might close the factories and that means they will not have any money, so maybe they are trying to support the other topic because they want money (P22, Q1)*

After engaging in the second set of activities (Q2), none of the participants had naïve views of differences in views of scientists, and one participant did not respond to the questions (Table 6). Three participants (18.7 %) came up with similar intermediary views in different scenarios of developing different views (Table 6). The participants mentioned that scientists develop different views based on information or evidence they collect from their readings and experiments, as shown in the excerpts below:

Scientists have different views based on the evidence collected from the experiments (P12, Q2)

Scientists will support different views based on the different knowledge they develop by researching, reading articles, experimenting, collecting data and evidence (P19, Q2)

One of the participants highlighted the importance of the agreement among the scientists because she thought that the government and businessman make decisions based on what scientists say, as shown in the excerpt below:

[It is a problem if the scientists do not agree] because every point of view in the government or the economy or business is all affecting one scientific idea. It is affecting the others in a bad way or a positive way (P2, Q2)

After engaging the second sets of activities (Q2), the number of participants having informed views increased to twelve participants (75%) (Table 6). These participants mentioned more than one idea regarding the differences in the scientists' views, such as the differences in their background knowledge and experiences. Most of these participants claimed that scientists support a certain view depending on the tests they perform, the research they do, and the information they collect. The data collected by scientists lead them to think differently and affect their beliefs, as shown in the excerpt below:

> *Different researchers have done different researches from different websites, and they have tried it and didn't help them to solve their tooth cavity and had negative effects on their body, so that's why they have different opinions (P8, Q2)*

> *Scientists support certain views because every scientist has a different point of view which make them find one information more logical than the other (P11, Q2)*

> *Scientists support different views and take different decisions regarding an issue based on their knowledge developed by reading articles, as well as according to their benefits (P20, Q2)*

A few participants also mentioned that scientists or individuals might support a certain position only if it helps them to profit more or receive more benefits, as illustrated in the excerpts below:

> *Maybe their point of view and the data that they get from their experiments are different. Most scientists want to protect their job, for example, people making technology if they decided that model A is correct then the technology will be less, and they won't get as much money, but if model B is correct they will still*

have their jobs, but it is not helping people with their money and staff, so they are trying to support specific models because they don't want to lose their jobs and they want money (P22, Q2)

I think that some of the scientists might think that this certain topic this model makes more sense to them and we could benefit from it more than the other topic, so they support it. They are convinced by their facts and evidence (P14, Q2)

Several participants considered that the disagreement among scientists might lead to confusion in society as people and governments make decisions based on the knowledge that scientists agree. These participants claimed that governments, people, and companies are influenced by the perceptions of the scientists positively or negatively. For this reason, the participant thought that scientists might sometimes not report the negative effects as seen in the excerpts below:

Some people study it differently than other people. Some people may discover something bad in fluorine, and the other group discovers something new, but they don't really want to publish the negative [it is a problem if the scientists do not agree] because every point of view in the government or the economy or business is all affecting one idea .. It is affecting the others in a bad way or a positive way (P5, Q2)

Different researches. They have done different researches from different websites, and they have tried it and didn't help them to solve their tooth cavity and had negative effects on their body, so that's why they have different opinions people will start to believe one of the opinions, and maybe they do the *bad thing that is, the thing the bad opinion. But scientists still did not discover that it is harmful and its negative effects. That's why there should be one opinion so that all people follow that opinion (P8, Q2)*

[It is a problem if scientists do not agree] because if model B is the right one we should be putting a lot of fluorine in the water we could be damaging a lot of people but if model A is the right one it helps the humans and anybody who uses fluorine in water to prevent tooth cavities. (P9, Q2)

After engaging in the third set of activities (Q3), one participant did not respond to the question about the differences in views of scientists, and none of the participants had naïve views. Two participants (12.5 %) showed intermediary views. These participants thought that scientists develop different views based on the difference in their knowledge about the issue, as shown in the excerpt below:

What they know about the topic. The data they know about electromagnetic waves (P2, Q3)

After engaging in the third set of activities (Q3), twelve participants (75 %) had informed views of differences in views of scientists (Table 6). They mentioned more than one informed view about how scientists may have different views about a topic. Several participants mentioned that scientists or individuals might support a certain position only if it helps them to profit more or receive more benefits, as illustrated in the excerpts below:

Some people say that it [EM] harms because they are caring for their health, and they are very strict while other people… [The other scientists] NO they care, but they have like they also care about their factories… they give *importance to the money. They are gaining from electromagnetic waves. They support model (P16, Q3)*

Maybe their point of view and the data that they get from their experiments is different, and most scientists want to protect their job, for example, people making technology if they decided that model A is correct then the technology will be less, and they won't get as much money, but if model B is correct they will still have their jobs, but it is not helping people with their money and staff, so they are trying to support specific models because they don't want to lose their jobs and they want money (P22, Q3)

A few participants mentioned that the personality traits of people, such as empathy and emotional wellbeing, affect the views that they develop and the decisions they make as illustrated in the following excerpt:

If you are a positive person and you want to stay positive, you always think that no it does not give you diseases to not worry about it so you can choose if you want model A or model B even you are forced to believe in one of them (P8, Q3)

One participant mentioned the influence of having different languages on developing meaningful ideas and certain views as seen in the following excerpt:

Because they are different people like different languages, different meanings, different people. They just have different minds. (P9, Q3)

Similar to the analysis of responses of the second and third sets of activities (Q2 and Q3), after engaging in the fourth set of activities (Q4), one participant did not respond to the question about the differences in views of scientists. And none of the participants had naïve views. Three participants (18.7 %) showed intermediary views.

They thought that scientists support a certain view depending on which of the available valid and current scientific knowledge they find logical as shown in the excerpts below:

> *Scientists support a certain view because the model they support is more valid based on the scientific knowledge they have on this issue (P11, Q4)*

> *Scientists support a certain view based on what they think is more logical and well researched (P15, Q4)*

After engaging in the fourth set of activities (Q4), the number of participants having informed views (75%) did not vary (Table 6). Twelve participants had informed views of differences in the views of scientists. These participants mentioned more than one idea regarding the differences in the scientists' views, the importance of the agreement among scientists, and its influence on the governments and societies. Most of these participants claimed that scientists support a certain view depending on the tests they perform, the research they do, and the information they collect. The data collected by scientists lead them to think differently and agree on a certain claim. Moreover, agreements between scientists on a certain claim help people in society make more informed decisions, as shown in the following excerpts:

> *Because all scientists when they grow up they will definitely have other opinions than others. They will think more scientifically or in another way. So, they might think of different opinions, but sometimes they may be wrong. [They have different views] because of what they have seen. Maybe, they have done animal testing. They have seen how it is working, and they are really disgusted (P8, Q4)*

> *Different people do not have the same background or scientific knowledge. So, they understand as much as they have scientific knowledge, that is, they produce*

what they know. Second, experience and the experiments [they have conducted]. So, how much they do research and study this thing. How their mindset is and how much you are open-minded (P5, Q4)

Several participants mentioned that the personality traits of people, such as empathy and emotional wellbeing, affect the views that they develop and the decisions they make as illustrated in the following excerpts:

People who think it is ok to do animal testing, I don't think they care about animals. They think that animals are not important. They care less about animals, and they don't try to help the animals. Their personality and benefit, that is, their type of personality. The people that are caring and nice support Model B. They care about animals because they love animals and think about how animals can help us in the future. But people who don't care about animals, I think they will support model A because they don't care about the animals and don't care if the animals are suffering (P22, Q4)

The feelings towards animals, like if someone doesn't like animals, it will not make any difference for him if the animals are killed. Emotions, feelings, and points of view that we have about the animals [might cause differences in views. For example, if I like animals, I don't want them to get harmed, and I will be supporting model B. But if another person doesn't like animals like P-9 will be supporting model A and will not make any difference for him if they kill a large number of animals (P14, Q4)

Analysis of the responses in the post-test indicated that none (0%) of the participants had naïve views about the differences in the views of scientists (Table 6).

The participants having intermediary views slightly dropped to two participants (12.5 %) (Table 6). These participants claimed that different scientists end up developing different conclusions because they have different background knowledge about the topic, as shown in the excerpts below:

> *They arrive at different conclusions because, based on the scientific knowledge they have and different points of view (P11, post).*

> *They experiment and analyze things differently, and in case they think it [other thoughts] was wrong they will disagree (P21, post)*

The number of participants having informed views about differences in views increased to 87.5% in the post-test (Table 6). The majority of the participants were able to develop informed views about the reasons why scientists develop different views about a particular topic. These participants explained that scientists have different views because they visualize, comprehend, and think differently as they have different background knowledge, experiences and mindset. Few participants mentioned that scientists might read various articles and develop their point of views accordingly, as seen in the excerpts below:

> *They may have different points of view and different data. Their way of thinking is different than others. Maybe because they have different points of view [developed] from the different experiments they have done and the different results that they have got. They will tell that this is exact, and this is not exact, depending on what the experiment is. (P2, post)*

> *[Scientists have different views] based on the experience they have, based on the information of research studies, based on articles [that they have read]. It is*

regular for scientists to disagree. Different people have different scientific knowledge which leads to different points of views (P5, post)

[They see things differently] maybe the types of the devices and the websites [they have used or read] …or what they have done before ... their experiences that are done before so that … like everything that scientists do or practice on. *Maybe they are different from the other scientists do. So, they have a different way of detecting things, maybe it is correct, or maybe it is wrong or might lead to the same answer. They use different steps and ways to see things (P8, post)*

No, because everyone has a different mindset because they both have different minds. Maybe because they visualize differently. Maybe they have done tests, and maybe they have seen things differently. No, it doesn't surprise me [that scientists have different views] as it all is the mindset. Everybody has different opinions. Maybe someone thinks that water fluoridation is bad for you, and it is a cheap way, but people are different; everybody has a style of thinking for doing everything. (P9, post)

Different scientists have different points of view regarding different issues. They have different knowledge and experiences. The way people think is different. My classmates and I don't think the same way. We are different than another one. All people have a different issues towards something. Maybe a scientist will think that this is not 100% accurate while the other meeting that was accurate and there is nothing else in the atom than this stuff. They will debate, and they will have a different point of view. It is something in the human nature that they have a different point of view (P14, post)

Scientific practices and knowledge construction. As shown in Table 7, the analysis of the pre-test showed that the participants were not classified as having informed views of scientific practices and knowledge construction. On the other hand, analysis of the responses in the pre-test revealed that one participant did not answer the question. Out of the sixteen participants, seven (43%) had naïve views of scientific practices and knowledge construction. These participants considered that scientific practices for knowledge construction are limited to performing tests and experiments in the laboratory, as seen in the excerpt below:

> *[Scientists construct scientific knowledge] by trying experiments … maybe using chemicals (P8, pre)*
>
> *They [scientists] produce scientific knowledge by experimenting (P4, pre)*
>
> *They [scientists] test it like in the lab. They do like a test on it like put it in stuff and test its physical stuff to know if it is safe to eat or if it is poisonous (P14, pre)*

Moreover, analysis of the pre-test responses showed that half of the participants (50%) had intermediary views regarding scientific practices and knowledge construction procedures (Table 7). These participants believed that scientists construct knowledge by thinking and analyzing logically. They described the practices of scientific knowledge construction as collecting evidence and facts through analyzing the available data, as shown in the experts below:

> *Scientists construct scientific knowledge using their logic and common sense (P9, pre)*

Scientists produce scientific knowledge by researching thinking analyzing in every possible way to give conclusions that turn into facts laws and theories (P5, pre)

Scientists construct knowledge by showing real facts and proof (P12. Pre)

Scientists construct scientific knowledge by collecting real facts (P16, pre)

Table 7

Frequency Distribution and Percentages of Students' Views of Scientific Practices and Knowledge Construction Theme

FRA Wheel Category	Scientific Practices and Knowledge Construction Totals (*N=16*)					
	Pre	Q1	Q2	Q3	Q4	Post
Naïve	7 (43 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)
Intermediary	8 (50 %)	4 (25 %)	2 (12.5 %)	3 (18.7 %)	2 (12.5 %)	3 (18.7 %)
Informed	0 (0 %)	4 (25 %)	8 (50 %)	8 (50 %)	7 (43 %)	12 (75%)

1. Pre: Pre-test, Q1:1st set of activities, Q2: 2nd set of activities. Q3: 3rd set of activities, Q4: 4rt set of activities, Post: Post-test
2. The total number of participants may not be 16 as the participants, who did not respond to the question, were excluded.

Among the participants who were classified as an intermediary, one participant mentioned the role of drawing and imagination in constructing scientific knowledge, as seen in the excerpt below:

Scientists construct knowledge by taking tests, drawing, and imagination (P10, pre)

Another participant classified as having intermediary views mentioned that scientists construct knowledge by conducting research, as shown in the excerpt below:

Scientists produce scientific knowledge when they do research and go on an adventure around the world (P21, pre)

Analysis of the questions of the first set of activities (Q1), in the context of climate change, showed that half the participants did not respond to the question. On the other hand, half of the rest of the participants (25%) showed intermediary views on scientific practice and knowledge construction (Table 7). Several participants mentioned that scientists construct knowledge by collecting facts. However, it was clear that after engaging in the first set of activities (Q1), many participants developed ideas about how scientists communicate, share ideas, and validate data as shown in the excerpts below:

Maybe before it was an opinion, then they take it to clarify. Then, they change it into fact for example, after the scientists approve that how will the atom looks like (P16, Q1)

Scientists share their opinions and agree on a certain knowledge (P2, Q1)

Scientists work together and check which claim is more convincing. They work together if they are not main rivals. They should have one opinion (P8, Q1)

The other 25% of the participants who showed informed views on scientific practices and knowledge construction procedures claimed that more than one scientific practice that allows scientists to construct scientific knowledge (Table 7). These participants stated that scientists conduct research, collect evidence, and suggest theories to build knowledge. However, in parallel, they gave examples of situations where scientists share their opinions to develop knowledge, as shown in the excerpts below:

I mean, when they [scientists] do research, they will probably still need time, but in the meantime, they come up with a theory or solution or what is happening and everything. But after a certain time, they will talk to each other to know, and they will know. If the theory is correct or it is false, they tell after the research what they got as a result (P5, Q1)

Analysis of the open-ended questions of the second set of activities (Q2), in the context of water fluoridation, showed that none of the participants had naïve views of scientific practices and knowledge construction and that six participants (37.5%) did not respond to the question about scientific practices. On the other hand, the number of participants showing intermediary views decreased to two participants (12.5%), who focused mainly on the scientific practices of sharing data, debating and convincing others with certain scientific information as illustrated in the excerpts below:

Each of them [scientists] will put their research on the internet, and if others are convinced with their research in Japan, they will be convinced with your research. Their ideas and share opinions (P16, Q2)

A different group of scientists shares their conclusions after they research and perform more experiments (P20, Q2)

After engaging in the second set of activities, 50% of the participants showed informed views on scientific practices for knowledge construction (Table 7). For these participants, to construct scientific knowledge, scientists repeat and analyze their experiments several times to validate their findings. In this process, scientists may find new information. Scientists discuss the available data and discuss each other's' opinions to compromise and end up agreeing on one conclusion. Some of the participants mentioned that scientists share their opinions and engage in argumentation by writing articles and posting them on websites. These views are illustrated in the excerpt below:

> *They will check and recheck what they did. They analyze how they got the results that prevent tooth cavity. Maybe they discover new things. Maybe start debating and maybe start to work together to maybe. Maybe both of their opinions will make another opinion and another fact. They need to talk together to end up with one answer, a fact. They see what the two groups of scientists do, and they try to figure out a way, another way to calculate to experience and to find the opinion or the fact (P8, Q2)*

> *Maybe they share ideas [to agree at the end] and data. Maybe they find something that will help them to come up with a solution in articles and websites. Scientists write articles to convince other people they do arguments responding to each other's information then they come up with solutions (P5, Q2)*

> *They read several websites and tried to conclude that maybe all of this makes more sense, and they put as one conclusion of their article. They do a debate and decide on one decision. And this decision spreads among the others (P10, Q2)*

> *They looked at different points of view, and they got more data and evidence, and in the end, when they saw the other point of view, they understood what other people see, and they knew how their idea seems correct. They should meet,*

talk to each other, and listen to the other points of view on websites. They state their ideas to the other website. The other group of scientists proves that that website is wrong by putting it [information] on their website and they debate over it on the websites (P22, Q2)

One participant explained that scientists add to the already existing knowledge and compare data of different resources, as seen in the excerpt below:

One starts to tell facts about his ideas about water fluoridation. The topic that convinces the scientists the most will be certain information about fluoridation. One might write an article, and the other may add on data to his article. All of the articles are posted. I think they compared their data with each other to come up with a conclusion of all of these (P14, Q2)

Another participant mentioned that scientists formulate hypotheses and attempt to test them. He elaborated by stating that scientists publish the results of their research studies to inform others if they have accepted or rejected their hypothesis. To check their results, scientists perform more research studies, as shown in the excerpt below:

[Scientists construct knowledge by] research and hypothesis. They think about something and then experiment it. If they are right, they publish it, and if they are wrong, they publish it to tell they were wrong. They need to talk about it and discuss it. If they find something new, they say that this is connected to this, and if they are not sure about it, they can do more research about it, and in the end, they might find the answer. (P9, Q2)

After engaging in the third set of activities (Q3), none of the participants had naïve views on scientific practices and knowledge construction (Table 7), while five participants (31.2%) did not respond to the question related to this theme. Three participants (18.7%) *who* showed intermediary views considered that scientists construct scientific knowledge as they collect data from experiments or readings, share their knowledge, the debate in case of differences in views, and agree on one opinion by convincing each other. These views are illustrated in the excerpts below:

> *Scientists gather information from gathering different articles and debate to reach an agreement, which will be considered as scientific knowledge (P4, Q3)*
>
> *They should write articles trying to debate, convince other scientists and prove facts with evidence so they should agree on one topic (P14, Q3*

Analysis of the questions at the end of the third set of activities (Q3) showed that half of the participants had developed informed views of scientific practices and knowledge. These participants mentioned that scientists write articles and publish them as a method of sharing ideas with others. In case of differences in opinions, scientists debate and compromise to end up with common opinions that are classified as scientific knowledge. These views are illustrated in the excerpt below:

> *First, they will share their information, see everything common, and then compare. They write articles and publish them so they can inform people if electromagnetic waves are dangerous or not. They try to debate to explain what they have done and show that each scientist tries to see the mistakes of the calculations they have made. If they are wrong, they correct them and definitely come up with one or new opinion (P2, Q3)*
>
> *They are making conclusions of the experiments research [and developing] scientific knowledge. They will write articles and debate then they will share*

these data, experience and background knowledge with each other once they Debate and argue and find the solution, and then it will be solved (P5, Q3)

If anyone around the world happened to him something, they can report the scientists or any person to analyze first they will see the mistakes they have done before so that they correct things, combine all the evidence and proof that they have like both scientist and come up with a new thing different than Model A and B. They might find a model C. They can work together, debate and while debating they can tell each other what they have done and the proofs they have found so both of them really discuss about it and see what would work (P8, Q3)

Analysis of the responses of the open-ended questions after the fourth set of activities (Q4) similarly showed that none of the participants had naïve views of scientific practices and scientific knowledge construction while six participants (37.5 %) did not respond to the question related to this theme. The number of participants having intermediary views dropped to two participants (12.5%) (Table 7). These participants thought that scientific practices for knowledge construction are limited to sharing an idea and debating. One of the participants mentioned that internet is involved in scientific knowledge construction procedures as shown in the excerpt below:

They will debate and see different solutions. They forget about their opinions all scientists [consider] like nothing has happened and try to see what they could do. They can find another solution of animal testing not to harm animals or humans (P8, Q4)

Scientists construct knowledge using the internet (P4, Q4

After engaging in the fourth set of activities (Q4), seven participants (43%) showed informed views regarding scientific practices and knowledge construction. These participants provided more than one informed idea about scientific practices. These views included performing experiments, conducting research, writing articles, sharing results, comparing data, and engaging in debate and argumentation to agree on one decision as shown in the excerpts below:

> *They have to share their information and tell each other there point of use and experiments and things and compare information and data, and after getting to an ending they will write an article and post it on the internet, and the other scientists will refute the article if they are against it (P2, Q4)*

> *Experiment and research. Scientists write articles to share knowledge. According to the data they believe in they write articles and do argumentation at the end (P20, Q4)*

> *By listening to other people's points of use and if scientists want to decide on one model. They should meet maybe not meet, but they should talk to each other and listen to each other, and they have to see the common evidence and common data to come up with a decision (P22, Q4*

Analysis of the post-test showed that one participant did not respond to the question. Moreover, none of the participants showed naïve views of scientific practices and knowledge construction (Table 7). On the other hand, the number of participants having intermediary views was three (18.7%). These participants added to their naïve responses of the pre-test only one practice performed by the scientists to construct scientific knowledge. In addition to conducting experiments, they mentioned that scientists write articles or engage in argumentation, as shown in the excerpts below:

[Scientists construct knowledge] by writing articles and doing more experiments (P12, post)

Write articles and do argumentation at the end (P20, post)

Furthermore, the analysis of the responses to the post-test showed a remarkable increase in the number of the participants had informed views on scientific practices and knowledge construction from 43% to 75% (Table 7). These participants were provided informed views on how scientists construct scientific knowledge. These participants claimed that scientists construct scientific knowledge by questioning, hypothesizing, researching, finding data and evidence through observation and experimentation, negotiating with other scientists and listening to their points of views and compare ideas, finding commonalities between results, writing books and articles for websites and sharing their knowledge so that everyone can learn from it. These informed views are illustrated in the following excerpts:

When they [scientists] research, get evidence and data, they negotiate and listen to different points of view. They do many experiments, and they do a lot of research, and after that, they are far with their research then they communicate with the other scientists, and they see the different things that they came up with and the common information they just do more experiments, and in the end, they will go into have an idea a specific idea out of the common ideas that the other scientists have come up with. And they communicate in website and books so that it can get around the world so that people can study it (P22, post)

They come up with a hypothesis, and then they try to prove it by the experiments done in the lab by the evidence shown. For example, if they want to test how the diamond was formed. The hypothesis will be like it is made up of carbon. If they see the diamond and the carbon to retest the chemical reactions they are safe to use with our bare hands or not. They write articles communicating the people and telling them about this issue that they discovered and created so that all the people will be convinced with them, and it will be safe to use. New things will be produced that have benefits to them scientists were studying about it and testing things about it. They were creating more articles and posts that changed you are mind toward something (P14, post)

Basically, they will be searching for answers. Every discovery starts with a question. For example, why does the volcano erupt? That they have to go and check out searching for evidence to back up their idea. They will be watching and experimenting. They construct knowledge by reading about facts reading about evidence and about past discoveries. Maybe because you need this old discovery to discover something new. Maybe part of this missing and you need to find that part. Like something old, you need to research, that's why they have these articles online. They experiment on things. They have a hypothesis and try everything they have, and if it does happen, it happens. Everything they have and at the end, they have a clear answer they may need to share the facts and everything learned from the discovery and connect everything and see which one is right and see the answers to the things that they are searching for (P9, post)

Relationship between science and society. Table 8 shows the results of the analysis of the responses of the participants to the pre-test regarding the relationship between science and society. This analysis showed that none of the participants had informed views of the relationship between science and society, while three participants did not answer the question. On the other hand, out of the sixteen participants, five participants (31.2 %) were classified as having naïve views (Table 8). These participants claimed that science is not related to society, as seen in the excerpt below:

Both society and science are not related. They are two different ideas (P4, pre)

Science is not related to society because society is people around us, while science is about nature and biology (P10, pre)

Science and society are not related to each other because they do not have similarities (P16, pre)

Analysis of the responses of the pre-test also showed that 50% of the participants had intermediary views about the relationship between science and society (Table 8). A number of these participants claimed that science is related to society because it enhances people's lives and provides benefits such as technological and medical innovations as illustrated in the excerpts below:

Science is related to society because it can help society in many ways (P18, pre)

Science is related to society because scientific discoveries like technology are essential for today's lifestyle (P14, pre)

Science is related to society because society makes use of scientific discoveries (P9, pre)

Science is related to society because science is related to the health of people. Science helps in finding medication and cure for diseases (P8, pre)

Moreover, five participants stated that science is related to society because people discuss science, as it is available everywhere, as shown in the excerpts below:

The society may talk about scientific topics (P5, pre)

Science is related to society because science is all around us (P22, pre)

Finally, one participant related science to society in the context of environmental issues as seen in the excerpts below:

Science and society are related because pollution and climate change can be related to society (P11, pre)

Table 8

Frequency Distribution and Percentages of Students' Views of Relationship of Science and Society Theme

FRA Wheel Category	Relationship between Science and Society Totals (*N=16*)					
	Pre	Q1	Q2	Q3	Q4	Post
Naïve	5 (31.2 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0%)
Intermediary	8 (50 %)	7 (43.7 %)	7 (43.7 %)	5 (31.2 %)	5 (31.2 %)	6 (37.5 %)
Informed	0 (0 %)	8 (50 %)	9 (56.2 %)	9 (56.2 %)	7 (43.7 %)	9 (56.2 %)

1. Pre: Pre-test, Q1:1st set of activities, Q2: 2nd set of activities. Q3: 3rd set of activities, Q4: 4rt set of activities, Post: Post-test
2. The total number of participants may not be 16 as the participants, who did not respond to the question, were excluded.

Analysis of the open-ended questions of the all sets of activities (Q1, Q2, Q3, and Q4) in the context of climate change, water fluoridation, electromagnetic wave pollution, and animal testing, as well as the post-test questionnaire, resulted in nearly similar classifications of participants into naïve, intermediary and informed.

At the end of the first set of activities (Q1), the number of participants having naïve views on the relationship of science and society sharply dropped from 31.2 % to 0 % while one of the participants did not answer the question (Table 8). Seven participants (43.7 %) had intermediary views on the relationship between science and society. Most of these participants related climate change, which is a scientific issue, to people in society because they are contributing to harming the environment by their activities. Others claimed that the environmental crisis due to climate is harming people and the environment as seen in the excerpt below:

The society is part of climate change. Human activities that humans are doing in their lives cause pollution. (P4, Q1)

Maybe the ice is melting, and the level of the sea is rising [leading to] floods (P12, Q1)

If there is too much sun. The sun will burn the plants, and people will not have any food. The polar bears are dying (P20, Q1)

Other participants claimed that science is related to society because people in society have their own opinions regarding scientific issues as seen in the excerpt below:

Every person in society has many opinions about scientific issues (P15, Q1)

Everybody is arguing and talking about climate change and weather change (P20, Q1)

Another participant claimed that science changes people's lifestyle as it provides technological devices as seen in the expert below:

Science is related to society because our lifestyle improves because of science (P10, Q1)

After engaging in the first set of activities (Q1), already half of the participants (50%) were able to develop informed views of the relationship between science and society. These participants provided more than one informed idea to describe the relationship. Several participants mentioned that the environmental crisis influences people's lives, habitats, and jobs. Once scientific issues like climate change negatively affect people's lives, they start to argue, protest, and create certain social movements. On the other hand, scientists try to come up with solutions to environmental issues, as shown in the excerpts below:

Maybe in a certain country, it will be very hot, and we can't live there. People like the farmers … because of climate change, the plants will not be able to survive so that the farmers will lose their job, causing us not to eat healthy and fresh food, so people who may use more money. The glaciers are melting, and the sea level is rising. People next to the water might lose their houses maybe they need a new house, and maybe they don't have enough money to buy one, and they will go, and participant in protest for this reason since a lot of people nowadays argue about different topics (P14, Q1)

Yes because it [science] makes us know more about our lives and makes people become more aware stuff happening every day. Like climate change is a problem our air. And science is showing it to us so that we do something about it … some plants are dying, and maybe in some places, water is drying up, and animals are not able to live, and humans need to eat plants and animals to live. The farmers and planters are not going to have money if they can't plant anymore. They will not have food, and they will not have money, and they will not survive (P22, Q1)

One participant mentioned that not all issues in science are related to society. He related science to medical issues. However, he said that that the sun is related to the society but not the changes in the planets as demonstrated in the following expert:

It is related to the society because it will let people be aware that we are damaging the climate and it is not from the solar system. It is important because, like if the sun heats, the temperature will increase and we will be like burning and it will cause cancer for some people (P16, Q1)

At the end of the second set of activities (Q2), none of the participants had naïve views about science and society relationships (Table 8). The number of participants having intermediary views remained constant at seven (43.7%). Several participants discussed how people in society use scientific products, while others mentioned that scientists give recommendations to the people about ways of using certain products as shown in the experts below:

A scientific product like fluoridated water is applied on and used by the people in the society (P20, Q2)

Water fluoridation is related to people when they drink and have health issues it harms the society that's drinking from it (P12, Q2)

It [fluoridated water] might harm people (P10, Q2)

Another participant thought that science is related to society because people in society engage in argumentation regarding scientific issues as they have different opinions as seen in the excerpt below*:*

The society may have two positions as well. Some agree that it's [water fluoridation] not good for the body and some say the opposite (P18, Q2)

At the end of the second set of activities (Q2), the number of participants showing informed views of the relationship between science and society increased slightly to nine participants (56.2%) (Table 8). These participants mentioned that people and governments shape their opinions and make decisions based on the results of scientific experimentation. So, some of the participants considered the agreement among the scientists on a certain claim very important. Or else, they thought that disagreements among the scientists might cause confusion in society and may affect people's decisions. Besides, several participants thought that, depending on people's decisions, scientific products might be sold or not. In this way, people in society may contribute to promoting the production of products that depend on scientific knowledge. These ideas are demonstrated in the excerpts below:

Yes, because also people will start to believe one of the opinions and maybe they do the bad thing. That is, the thing the bad opinion. But scientists still did not discover that it is harmful and its negative effects. That's why there should be one opinion so that all people follow that opinion. Society is basically the one to *decide if they want water fluoridation or not. They decide if they want to sell it or not, where do they want to sell it, how they sell it, the prices like the financial things. Science is medicine and things related to health they found out new things about nature that can help us and help anyone (P8, Q2)*

People saw the evidence and believed science more, and they said that adding a small amount of additional fluorine will help tooth decay (P4, Q2)

Because it affects people's healthy lifestyle and mood because scientists found that fluorine is maybe good and put in the water. Water affects society, and people start to theorize if it is good or not or if it is bad for the children. Some people say that it is good and other people say that it is wrong. If it is model B, we will stop or make less fluorine in the water and if model A is the right one they would put or wouldn't change the fluorine or they could put it in every country (P9, Q2)

Each of them [scientists] will put their research on the internet, and some people are convinced with that research. They say their ideas and share opinions. Like the society will drink water fluoride, and if some people caused the positive effect they will keep on drinking it but and with other people will have another opinion (P16, Q2)

Furthermore, many participants claimed that scientific innovations and discoveries improve the health conditions of the people in the society and protect them from health problems or diseases. People are at risk of not being able to control the amount of fluoride intake when fluorinated water is available to the public. However, when people have a choice to use or not use scientific innovations, their health problems will be their responsibility. People in society have to follow the decisions made by their ministry of health regarding medical issues recommended by experts. In case a scientific product affects people's health negatively, people in society may organize protests against the government, as shown in the excerpts below:

> *With water fluoridation, all the society would have healthy teeth by drinking water that contains fluorine that will prevent cavities and teeth decay. Through science, you can get new discoveries that are actually true, and some discoveries are related to health, such as medicine or bacteria, and are also related to how they influence us. I think that the government should not put fluoride in the water, but I think that they should put the bottles of water with fluorine in the pharmacies so that they get to choose their decision whether they want to get it or not (P19, Q2)*

> *When some people in society are affected negatively by scientific innovations, they organize protests. When people have the choice of water, in that case, it will be their responsibility. When we put fluorine into the water, people will not go to the dentists anymore, so that causes a change in the money in the society, and that might lead to protests. People are forced to obey what the government says. The ministry of health [takes the decisions] (P14, Q2)*

One of the participants interestingly mentioned that science, depending on its positive or negative influences and its capacity to create jobs that help people to make a profit, influences students' choices regarding the university majors that they want to pursue as shown in the excerpt below:

[When dentists start to profit less], it will not be useful for people to study things related to dentists in the university (P8, Q2)

At the end of the third set of activities (Q3), one participant did not respond to the question associated with the relationship of science with society, and none of the participants had naïve views of the relationship of science and society. Five participants (31.2 %) had intermediary views. Most of these participants thought that science is related to society because scientific products may affect the people in society in both positive and negative ways. These ideas are illustrated in the following excerpts:

People in society are being exposed to electromagnetic waves (P20, Q3)

They are being harmed by electromagnetic waves from other people. The whole society will be harmed because other people are making electromagnetic waves by their devices. From the devices from the routers (P16, Q3)

Almost all technology has electromagnetic waves. The society is exposed to the electromagnetic waves (P11, Q3)

One participant mentioned that people contribute in increasing the electromagnetic wave pollution in their surroundings as seen in the excerpt below*:*

Electromagnetic waves increased by society with time (P10, Q3)

Another participant also mentioned that people have the choice of supporting the use of scientific products or refusing them as shown in the excerpt below*:*

Everyone can choose to stop using routers or internet or phone and technology (P21, Q3)

Analysis of the open-ended questions of the third set of activities (Q3) showed that the number of participants having informed views remained constant at 56.2 % (Table 8). These participants had similar views regarding the relationship between science and society. Some participants mentioned that people in society promote the production of scientific products when they decide to buy these products. In turn, people are contributing to increasing electromagnetic wave pollution by using technological devices and emitting electromagnetic waves. Moreover, several participants mentioned that electromagnetic waves cause diseases and thus influence society. However, people are so dependent on technological devices; therefore, decisions taken by the government regarding reducing the utility of these devices may influence people's lives, as shown in the following excerpts:

> *Because society is buying technology. If society was not buying the technology, we would not have this problem. The society is buying technology, and it's making the electromagnetic waves this is why people are debating about it (P22, Q3)*

> *If technological devices harm people by electromagnetic waves, people like scientists or the government will stop producing more technology that causes electromagnetic waves, and this will really affect our habits. If people have diseases, the rate of diseases will increase, and some of us will die because of electromagnetic waves. When science discovers one medicine and techniques to heal someone, this will make a positive impact in someone's daily life (P16, Q3)*

> *[It is a problem if scientists do not agree] it takes more time to evaluate the final answer so maybe let's say it does cause cancer people are dying from cancer*

because of electromagnetic waves and if they still don't make up their mind whether Model B is right or model A is correct, and they keep the Wi-Fi. They should make an opinion really fast so that they had enough time to change the wrong stuff. They [scientists] are helping us to make new stuff's new discoveries like if someone's hand is cut off, they can make prosthetic arm they find a new element that they may use it for a new medicine (P9, Q3)

Another participant claimed that the academic books used by the students are edited and updated based on the newly discovered scientific knowledge, as shown in the excerpts below:

It [scientific knowledge] will be what people follow, and it will be scientific information, scientific knowledge then maybe they will write it in books for children to study at school (P22, Q3)

At the end of the fourth set of activities (Q4), four participants did not respond to the question associated with the relationship of science with society, and none of the participants had naïve views of the relationship of science and society. The number of participants showing intermediary views remained constant at 31.2% (Table 8). Similar to the responses of the previous questionnaires, many of these participants thought that science is related to society because scientific products may affect people and animals in society in both positive and negative ways. Few participants discussed the ways scientific products are used by people in society. These ideas are illustrated in the following excerpts:

People are being protected because of animal testing (P15, Q4)

I could relate animal testing to people in society that scientists could do testing on animals instead of testing on humans (P21, Q4)

Science is related to society because it finds solutions to people's health problems and keeps humans protected from diseases (P10, Q4)

After engaging in the fourth set of activities (Q4), seven participants (43.6%) were classified to have informed views regarding the relationship of science and society because they provided more than one informed view to describe this relationship (Table 8). Many of the participants claimed that science helps and protects people in society by giving medications. Some of the participants mentioned that people make decisions concerning their health and food based on the scientific knowledge that is not necessarily available online. Moreover, some participants said the ways people may disagree about scientific issues, argue, and oppose others' opinions, as shown in the following excerpts:

Maybe a lot of people want to save the animals; these are who go vegan or vegetarian. They just don't want to eat the meat of animals. So they might write articles and online posts because now everything is online and they can rent why we should not hurt the animals. They might make like protests. Yes. There might be severe clashes, and this may backlash the government who is telling the scientist "yes you can do animal testing," and they are also helping them what they need to do animal testing (P9, Q4)

One of the participants added that not standing against a particular act like animal testing is a way of supporting that act, as shown in the excerpt below:

Society has to decide if they want to do animal testing or not. Scientists might have made a mistake, and maybe they have realized something about animal testing, a not after a day, let's say, so they don't know if they really the animal testing is a good thing because they think that. They have different cells, different mindsets, and different things [capabilities] how they digest or how they grow. Maybe what they have eaten encouraging animal testing. Society is trying to help the scientists to do animal testing because they are confirming that they are giving the animal. It is not like they are supporting them, but they are not standing against their opinions. So, they are helping them how to do animal testing because it may help the society by the medicine found as a result of animal testing. If they [scientists] have found a vaccine that it isn't working for humans, they can use animal testing [to improve it]. So society will definitely keep on supporting scientists to do more animal testing to find vaccines. (P8, Q4)

Some participants discussed the disadvantages and risks associated with certain scientific practices, such as animal testing. They also discussed the benefits of science. They thought that science helps people by providing technological and medical advancements. In parallel to the benefits, many participants mentioned the disadvantages of science and how it might cause changes in the people’s food diet, as illustrated in the excerpts below:

Animals have different reactions than humans; this might also mean that humans might die. Maybe a lot of people want to save the animals; these are who go vegan or vegetarian. They don't want to eat the meat of animals. So they might write articles and online posts because now everything is online, and they *can rent why we should not hurt the animals. They might make like protests yes there might be severe clashes, and this may backlash the government who is telling the scientist yes you can do animal testing, and they are also helping them what they need to do animal testing (P9, Q4)*

[The society is getting] mistrusted medication. We are not sure if the drug will work on us, so we test it on the animals. If the society or we get the wrong medication, it can lead to viruses, sickness and a lot of diseases that are harmful which can cause great damage in humanity (P5, Q4)

To know about some vaccines for humans, they tested on the animals. We are testing the animals for ourselves, which is society. So animal testing and society are related. We are trying to make the medicine that we need, and we are testing them on animals. Sometimes animal testing can be tested by technology like computers and electric machines. We can start doing them [animal testing] on technological devices and use new technology to stop animal testing (P4, Q4)

Analysis of the open-ended questions in the post-test showed that one participant did not respond to the question related to the relationship between science and society. Similar to the previous questionnaires, none of the participants had naïve views of this theme (Table 8). The number of participants having intermediary views was six (37.5 %). These participants mentioned one informed idea about the relation between science and society. Moreover, some of these participants considered that science is related to society because science is related to everything. Few participants discussed how people in society use scientific products. Several participants mentioned that scientists guide and give recommendations to the people about ways of using certain products, as shown in the experts below:

> *Science is related to society; for example, in water fluoridation, people know what does water fluoridation does. But to know how much is the amount they should take from this water and test it. Science is related to society because they give knowledge about how they may need things or not. For example, water fluoridation the need it large amounts or small amounts how to do you (P18, post)*

> *Scientists collect evidence or data to end up with a decision, and a proof that is a certain topic is right (P15, post)*

> *Because science is related to everything (P21, post)*

> *Yes. Society is related to science because science related to everything around us (P11, post)*

Analysis of the open-ended questions in the post-test showed that nearly half of the participants developed informed views regarding the relationship between science and society. These participants considered that science is essential for people because they benefit from science and its innovations. For this reason, people are dependent on scientific products. They thought that science helps people by providing technological and medical advancements. However, many participants mentioned several disadvantages of science as well. These included the hazards or the dangers that animals and people are subjected to because of the negative effects off scientific products and practices. Many participants said that people take part in science because they have to make decisions and raise awareness regarding scientific issues, as shown in the excerpts below:

> *Science is related to society because, without science, we couldn't live. For example, without animal testing, we would have tested on humans because we can't think of testing on the animal. Without science, we wouldn't know if animals are similar to humans. Without science, we wouldn't know what extra Fluorine causes and people will be endangered without science. For example, for the golden rice, maybe in the future, there will be no plants to survive. So, they have to do genetically modified food so that we can live. So they are always related to science and humans. Science is helping people, but sometimes it is disadvantaged. Science has advantages and disadvantages. The advantage is that they [scientists] can discover more things and test to get a better future because of science. Disadvantages may be that something goes wrong, causing the killing of the people. Or, maybe when we can't test on the animals, we should test it on humans, so these are some disadvantages (P14, post)*

> *The easiest example that I can get is that it is water fluoridation because it is all about the society and the health of society. Science is everywhere, and Society is part of the science because if the society takes the wrong medication, it can lead to problems which are from the cause of science (P5, post)*

> *Society uses sciences in their everyday life, so I think it is related because society is making technology and science. They are following the science to get more advantages in life like in technology. They are following the science to make it [technology] more advanced. It is happening in our daily lives because,*

for example, regarding animal testing, the society is fighting to find the answers because if animal testing kept going, it might affect the society in a bad way. Also, the electromagnetic waves are related to society because society is exposed to electromagnetic waves. Also, climate change is affecting society because actually, the society is affecting the climate change because they are the ones who are polluting, but it is going to affect them later because the temperature in the country will make the water dry in the country and they will die, so it is affecting them also (P22, post)

It is related because maybe they [scientists] found the discovery that this is bad for you, and they talk about it. It is connected to society because people can make blogs and articles about this thing and maybe spread awareness about something dangerous for species. So they have to raise awareness about it, and maybe they say "don't go to that area." They will tell what the dangers for society are. Maybe scientists find out that water fluoridation is bad for you. They have to tell everybody in the world that is bad for you don't drink it or maybe it will kill you or cause cancer (P9, post)

Science makes our world better because society will agree or disagree with scientists. Scientists discovered things that are now laws. Maybe scientists are forcing them (people) to sell genetically modified food. You won't really know like society would agree that if it is a good thing or not because they have different opinions. So, we may think that they [people] might be convinced that it should be sold (P8, post)

Relationship of science and politics. Analysis of the responses in the pre-test presented in Table 9 showed that eight participants did not answer the question while six participants (35.7 %) had naïve views regarding the relationship between science and politics. These participants stated that science and politics are not related to each other, as seen in the excerpt below:

> *Science is not related to politics because politics are related to history. History and science to do not work together (P8, pre)*

> *Science is not related to politics (P10, pre)*

Table 9

Frequency Distribution and Percentages of Students' Views of Relationship of Science and Politics Theme

FRA Wheel Category	Relation of Science and Politics Totals (*N=16*)					
	Pre	Q1	Q2	Q3	Q4	Post
Naïve	6 (37.5 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)
Intermediary	2 (12.5 %)	6 (37.5 %)	7 (43.7 %)	7 (43.7 %)	7 (43.7 %)	4 (25 %)
Informed	0 (0 %)	4 (25 %)	4 (25 %)	5 (31.2 %)	0 (0 %)	7 (43.7 %)

1. Pre: Pre-test, Q1:1st set of activities, Q2: 2nd set of activities. Q3: 3rd set of activities, Q4: 4rt set of activities, Post: Post-test
2. The total number of participants may not be 16 as the participants, who did not respond to the question, were excluded.

Additionally, analysis of the pre-test showed that none of the participants had informed views on the relationship between science and politics. Only two participants

(12.5 %) had intermediary views (Table 9). One of these participants thought that science and politics are related only in particular contexts, while the other mentioned that science might be part of the political agenda, as shown in the excerpt below:

Science is related to politics depending on the topic (P5, pre)

Politics talk about it [science] (P9, pre)

Analysis of the open-ended questions of the first, second, and third sets of activities (Q1, Q2, and Q3) in the context of climate change, water fluoridation, and electromagnetic wave pollution resulted in nearly similar classifications of participants into naïve, intermediary and informed.

At the end of the first set of activities (Q1), six participants did not respond to the question, and none of them had naïve views regarding the relationship between science and politics. However, six participants (37.5 %) showed intermediary views of this theme (Table 9). Several participants related science to politics by associating it with governments. They thought that politicians support science and contribute to improving scientific innovations, as shown in the excerpts below:

Science is related to the government (P8, Q1)

Politicians may help in solving certain scientific issues by improving industries (P18, Q1)

Few participants mentioned that people, who face financial problems due to scientific issues protest and cause political instability in the country as seen in the excerpt below:

It [science] is also causing us [people] not to eat healthy and fresh food. People will be protesting about this specific topic and cause a decrease in politics [political influence] which will damage the country (P14, Q1)

Finally, analysis of the open-ended questionnaires of the first set of activities (Q1) showed that four participants (25%) had developed informed views regarding the relationship between science and politics (Table 9). A few participants thought that governments make a profit from scientific innovations, and science may contribute to improving the economic situation of the country. Furthermore, with stronger economies, the political influence of the country increases. On the other hand, these participants claimed that the government finances scientists and engineers to conduct research or create new ideas. In case governments do not provide a certain budget to scientists and engineers, scientists are not able to conduct innovative research. Social problems such as unemployment lead scientists to protest against the government as seen in the following excerpts:

If the economics don't support science that much, that means they [scientists and engineers] can't invent and discover that much… They [politicians] will be less support to engineers who use and build stuff, and the government pays them ... so they [politicians] don't have money to pay people, and they might go unemployed, and they might not even get money and get against it [the government] (P9, Q1)

With science, you can have inventions that can get a higher amount of money, which means the economics will be higher. Without science, politics will argue over the economies. If we have scientific innovation, the economy gets higher. If *the economy gets lower, scientific innovations will get lower. I think without the economy without selling and [gaining] money, a country may not have any politics... everyone will start arguments like Model A and Model B (P19, Q1)*

Other participants thought that politicians consult scientists before making decisions. Sometimes, they discuss the application of particular scientific innovation because some politicians prioritize financial benefits, while others prioritize the health of the people or the environment. This disagreement may lead people to organize protests in society. For this reason, participants mentioned that, if democratic principles are applied correctly, people vote for the leaders who work for the benefits of society and the environment as illustrated in the excerpts below:

Maybe the politicians will fight about closing the factories because they want money in the country but some politicians, they care more about the earth, so they fight about that (P22, Q1)

Politics is voting to a president that wants less pollution and supports model A (P9, Q1)

At the end of the second set of activities (Q2), five participants did not respond to the question, and none of the participants had naïve views regarding the relationship between science and politics. Seven participants (43.7 %) showed intermediary views on this theme (Table 9). Some participants mentioned that governments make decisions regarding the application of scientific discoveries in the country based on the opinions of the scientists as seen in the excerpts below:

The government gives the order to add fluorine. When scientists agree on one topic, the government will know about it and force people to do this certain *thing. Although it might be not true, people are forced to obey what the government and the ministry of health say (P14, Q2)*

The results of scientific research persuade governments to make changes in the society like adding fluoride to the water (P11, Q2)

[It is a problem if the scientists do not agree] because the government takes decisions and every point of view in the government or the economy or business is all affected by that one idea... It is affecting the others in a bad way or a positive way. Political wise [politically] depending on the decision they make, it may lead to the society be forced to drink fluorine or not (P5, Q2)

Analysis of the open-ended questions of the second set of activities (Q2) showed that the participants thought that politicians argue and debate regarding scientific issues. They also thought that with stronger economic conditions, the political influence of the country increases. In the case of an economic crisis, one of the participants thought that governments might ask for financial support from different international organizations. On the other hand, these participants claimed that the government finances scientists and engineers to conduct research or create new ideas, as seen in the following excerpts:

Different politicians might fight about different points of view. Politicians might debate, and there might be protests. It affects the economy since if they support model A [fluorine prevents tooth decay]. Dentists will lose their jobs. If the answer is that of model B, the people that put fluoride in water will lose their jobs. Either way, the country will become weaker. The politicians maybe talk to other organizations, and so they have more money in the country. They support *a certain model to have more money in the country for the reputation of the country will go down. (P22, Q2)*

Other participants thought that politicians make decisions regarding the application of scientific innovation in a society based on the validation of the knowledge by scientists. That is, governments consult scientists before making decisions. Sometimes, they debate on the application of specific scientific innovations because politicians prioritize financial benefits, while others prioritize the health of the people or the environment. This disagreement may lead to organizing protests in society illustrated in the excerpts below:

They [scientists] check in every place if water has fluorine. If it has fluorine, they may tell the government that this water has fluorine, and they should stop it until we do further research. They are the ones that say to the government if the food is good or of it should be better, or there is something wrong with it. Maybe some governments in all places support this idea that fluorine is good for people and some don't. So some put fluoride in the water, and some other governments don't so they might have a discussion with each other. They might fight over which one is right (P9, Q2)

The ministry of health will give the order to put fluoride in the water-based on the scientific discoveries. I think that the government should not put fluoride in the water, but I think that they should put the bottles of water with fluorine in the pharmacies so that people get to choose their decision whether they want to get it or not (P19, Q2)

At the end of the third set of activities (Q3), four participants did not respond to the question, and none of the participants had naïve views regarding the relationship between science and politics. The number of participants having intermediary views remained the same at seven (43.7%) (Table 9). Some of these participants related science to politics because governments play a role in solving problems caused by scientific issues, as shown in the excerpts below:

The government may propose solutions to the issues related to science (P2, Q3)

This issue is related to politics because the government or politicians may help solve the problems related to EMW (P4, Q3)

A participant mentioned that governments make decisions regarding the application of scientific discoveries in the country based on the opinions of the scientists. In case the government refuses the use of certain scientific products, people in charge of manufacturing that product will face financial problems, cause instability and political problems as seen in the excerpts below:

The politicians are the one making the decision of having electromagnetic waves or not (P20, Q3)

The people who work jobs that require the technology the store closes because of electromagnetic waves people will lose their jobs and money will decrease jobs and unemployment of jobs will increase, and this will cause political problems (P14, Q3)

Another participant mentioned that governments and politicians might make a profit because of science, as shown in the excerpt below:

Some politicians are with selling cell phones so that they can make more money (P18, Q3)

Analysis of the open-ended questionnaires of the third set of activities (Q3) showed that five participants (31.2 %) had developed informed views regarding the relationship between science and politics (Table 9). These participants gave more than one informed idea regarding the relationship between science and politics. These participants thought that politicians make decisions regarding the application of scientific innovation in society according to the validations of the scientists. That is, governments may or may not agree with certain scientific issues and cause financial problems for people working in the field of science as illustrated in the excerpts below:

Electromagnetic waves are related to politics and economics because the government is the one that agrees to this issue and it does not agree to degrease electromagnetic waves so that the country and the companies won't lose money (P11, Q3)

It is connected immediately because the scientists acknowledge and government tries to make devices that do not have electromagnetic waves, or they are very low. If that happens, they will keep on sending it to people who are afraid of getting cancer. But if they still want Wi-Fi. it will give them a lot of money that is the economics will be high for electronics, and it will help the government a lot but the machines to make electronics will cost a lot (P19, Q3)

Many participants mentioned that politicians might make decisions regarding problems that are created by science. However, sometimes politicians support a specific claim to protect their financial benefits. They convince others to support their positions so that they keep on profiting from the production of technology, as shown in the excerpts below:

The decision governments take about this issue; maybe this is the political part. Besides the research, there are a lot of problems in the government that also makes it political which lead to a different point of views because they want their opinion to stand out and convince everyone because this will cause them an economical problem or financial problem. So based on their benefits, they don't want to show their mistakes because they don't want to lose anything financial or economic or political (P5, Q3)

[Science is related to politics because of] the government's decisions. If some parts of society support different models, and then the government makes a decision that might not help really help society. [With scientific information], it will be easier for the government to make decisions. If they want to stop technology but they don't know the answer, yet they will be confused if they stop the technology or not. They will be fighting about what decision they should make. But if they have the answer, it will be easier. Maybe in some countries, politicians might fight about the different models, and they won't know how to make a decision for society (P22, Q3)

However, in the context of animal testing, analysis of the open-ended questions of the fourth set of activities (Q4) showed that none of the participants showed naïve views on the relationship between science and politics (Table 9). Eight participants did not respond to the question. On the other hand, none of the participants showed informed views to relate science politics in the context of animal testing. However, the number of participants having intermediary views (43.7%) did not vary at the end of Q4 (Table 9). These participants mentioned that the relation of science and politics is limited to helping the government to make informed decisions regarding performing animal testing or replacing it with technology, as shown in the excerpts below:

> *[The role of the government is] to make the right decision and to build on evidence. For example, evidence 6 is developing and improving technology to replace animal testing (P5, Q4)*

> *To test medicine and check if they will work or not since people in society now know about like there is another way. So people will try to persuade scientists or even the government to choose the other way, but the government may decide to say no because it costs more money (P9, Q4)*

> *Since whatever scientists determine for example of animal testing is good then the government will force us to test on animals and not on humans although I don't support this (P14, Q4)*

Analysis of the answers to the questions of the post-test indicated the four participants did not respond to the question (Table 9). Only four participants (25 %) showed intermediary views when relating politics to science (Table 9). These participants claimed that the role of the government in taking decisions regarding scientific issues, as shown in the excerpts below:

> *Government is related because basically, the government controls everything. Basically, if all of the people are against it, they will shut down the factories (P2, post)*

The government can stop electromagnetic waves and animal testing. It can stop people from harming society… the government stops electromagnetic waves and technology in the places that people buy phones. People will not buy anymore because the government stopped it (P4, post)

On the other hand, in the post-test, the number of participants having informed views increased to eight participants (50%) (Table 9). These participants mentioned more than one informed view regarding the relationship between science and politics. They thought that science is related to politics because the governments promote the application of scientific discoveries that are approved by scientists because governments trust science, as seen in the excerpt below:

Science is related to the government because they [scientists] tell the government about it that it will be safely used. For example, if scientists discovered that extra fluorine is good, so the government is putting extra fluorine in the water. The government is doing what the scientists are proving. If the scientist is proving something right, they are doing it. They know more about it. They trust science (P14, post)

Governments work with scientists and organizations to give answers to society. Sometimes, for example, the government wants to shut down the factories because it is creating pollution, so they need to shut it down. The government is following the science to make different decisions (P22, post)

Others thought that politics is related to science because governments support scientists financially to conduct their research studies. Also, governments spend money to import new machinery and technology so that scientists can perform scientific research studies, as illustrated in the excerpts below:

The government may afford more money. They give more money to scientists to prove and do researches. (P16, post)

Yes, because some politicians can sell scientific ideas to other governments. For example, in animal testing, they can be more money and save the animals by bringing technology and computers to test the experiment then the medicine (P18, post)

Relationship between science and economics. As shown in Table 10, analysis of the responses in the pre-test indicated that, out of sixteen participants, nine did not respond to the question. While five participants showed a naïve view by mentioning that science and economics are not related to each other, as shown in the excerpt below:

No. Science and economics are not related because science explores new phenomena, but economics aims to represent graphs which depend on money (P21, Pre)

Another participant had intermediary views on the relationship between science and economics on the pre-test (Table 10). This participant considered that similar to the relationship between science and politics, science and economics may be related only in particular topics, as illustrated in the excerpts below:

Science is related to politics and economics depending on the topic (P5, Pre)

Finally, the analysis of the pre-test indicated that none of the participants had informed views on this theme.

Table 10

Frequency Distribution and Percentages of Participants' Views Relationship of Science and Economics Themes throughout the Study

FRA Wheel Category	Relationship between Science and Economics Totals (*N=16*)					
	Pre	Q1	Q2	Q3	Q4	Post
Naïve	1 (6.2%)	1 (6.2 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)
Intermediary	1 (6.2%)	4 (25%)	3 (18.7%)	4 (25 %)	5 (33.3 %)	4 (25%)
Informed	0 (0 %)	7 (43.7 %)	11 (62.5 %)	11 (62.5%)	3 (20 %)	10 (62.5%)

1. Pre: Pre-test, Q1:1st set of activities, Q2: 2nd set of activities. Q3: 3rd set of activities, Q4: 4rt set of activities, Post: Post-test

2. The total number of participants may not be 16 as the participants, who did not respond to the question, were excluded.

After engaging in the first set of activities (Q1) in the context of climate change, the number of participants classified as naïve about the relationship of science and economics dropped to one (6.2 %), while four participants did not respond to the questionnaire (Table 10). The participant who showed naïve view thought that science and economics are not related because economics is associated with money, while science is not as can be seen in the excerpt below:

> *Science is not related to economics because economics is related to money. Science is not related to money (P8, Q1)*

However, after engaging in Q1, more participants (43.7 %) showed informed views of the relationship between science and economics (Table 10). Several participants showed awareness about the increase in the unemployment rate in society due to both negative and positive effects of scientific innovations, as shown in the excerpts below:

> *They are related because if they close factories, the climate will be better, but economics will be destroyed because from the factories we will have good economics like if they had more money will be better and improved (P16, Q1)*
>
> *The workers, for example, after closing the factories they want to buy something, they don't have money. So, they can't really buy stuff, and the people who are selling will also not have money because they are not selling so the whole country will not have money (P22, Q1)*
>
> *Because when scientists find out that greenhouse gases and pollution are causing this, they might try to shut down factories and produce less money now. The government and the economics go down, and the country or whatever place they are in might go bankrupt. they [politicians] will be less support to engineers who use and build stuff, and the government pays them ... so they don't have money to pay people, and they might go unemployed, and they might not even get money and get against it [the government] (P9, Q1)*

These different views did not seem to change much over time. In the answers to the questions in the second set of activities (Q2), in the contexts of water fluoridation, five participants did not respond to the questions, while none of the participants showed naïve views regarding the relationship of science and economics. After engaging in the second set of activities (Q2), the percentage of participants with intermediary views on science and economics relationships was 18.7% (Table 10). One of the participants related science to financial issues as he thought that people spend money on expensive scientific products such as fluoridated water as shown in the excerpts below:

> *Water fluoridation will let people pay more. If they need fluoridated water, they pay more (P16, Q2)*

Analysis of the answers at the end of Q2 showed that the number of participants with informed views increased from 43.7% to 62.5 % (Table 10). More participants were able to develop more informed views to relate science to economics. Some of these participants thought that when scientific innovations affect people positively but at the same time affect the profession negatively. Additionally, more participants developed informed views about the influence of science on increasing the unemployment rate in the society. Few participants mentioned that certain scientific products are more expensive, leading people to spend more money on scientific products, a situation that affects them fanatically. These views are illustrated in the excerpts:

> *It affects the dentists, so if model A is true and fluorine prevents cavity, people won't go to dentists to fix their teeth, drink the water, and that is affecting financially. It helps the people financially, and it will decrease the intake [profit] of dentists (P4, Q2)*

> *If model A is correct that fluoride helps in the tooth cavity, people won't have to go to the dentist. They can prevent their teeth simply by drinking water. Many people might start getting cheaper water that doesn't contain fluoride or water that contains fluoride and it more expensive (P2, Q2)*

When we put fluorine into the water people will not go to the dentists anymore, so that causes a change in the money in the society and that might lead to protests (P14, Q2)

A few participants related science to financial issues when they mentioned that people would spend money to improve their health. Another participant said that people lose money by spending it on buying technological devices, which might cause problems in addition to benefits as shown in the excerpts below:

Since it [scientific products] causes cancer, everyone will be in the hospital because we need a cure, and no one will have a job. They will all be sick, and now if it is true that model A is causing cancer, the technology products will be selling less. There will be no money (P5, Q3)

They [scientists] want to sell technology, and they [people] are buying, and in another way, people are buying diseases and sickness. So in both ways technology is harmful. It is a bit of a waste of money to buy things that cause diseases and may harm you. Scientists are benefiting from this thing. Technology can help us in different ways and could harm us in different ways (P8, Q3)

Analysis of the open-ended questions at the end of the third set of activities (Q3) indicated that one participant did not respond to the question regarding the relationship of science and economics, and none of them had naïve views of this theme. However, four participants (25 %) showed intermediary views when describing the relationship between science and economics (Table 10). These participants thought that people make decisions regarding scientific issues based on their financial benefits. Others associated science with economics as they thought that many people profit from selling scientific products. Others related science to financial issues as they thought that people spend money on expensive scientific products such as technological devices or fluoridated water, as shown in the excerpts below:

Many people don't want to support model A because they don't want to stop selling devices so they can still gain money. Or else, they [people] stop buying electronic devices so they won't get cancer. The people who work in factories won't get money (P2, Q3)

Some people have more money, and they are becoming richer because of phones, for example, the Apple Store and any other phone stores, they have more money because of this technology (P4, Q3)

Some politicians are with selling cell phones so that they can make more money (P18, Q3)

After engaging in the third set of activities (Q3), the number of participants having informed views stayed constant at eleven (62.5%) (Table 10). Some of these participants thought that scientific innovations affect people positively, but also can lead to others being unemployed. However, few participants mentioned that certain scientific products are expensive, leading people to spend more money. These views are illustrated in the excerpts:

If people find out that technology can cause cancer, technology sales will go down majorly. They will all go bankrupt and will lose a lot of money. It will give them a lot of money that is the economics [business] will be high [increase] for *electronics, and it will help the government a lot but the machines to make electronics will cost a lot too (P9, Q3)*

Devices are producing this type of pollution after years. If this type of pollution causes cancer, no one will buy them [devices], and the companies won't have money, so economists and politicians will start arguing. On the other hand, we will get more technology and new devices, and society will get the phones with all the electromagnetic devices and will raise the economy. (P19, Q3)

Analysis of the responses after the fourth set of activities (Q4) in the context of animal testing showed that seven participants (43.7 %) did not respond to the question (Table 10), and none of them had naïve views of the relationship of science and economics. Nevertheless, the number of participants showing informed views on the relationship between science and economics decreased from 62.5% to 20% (Table 10). Only three participants were able to relate science to economics in the context of animal testing. One of the participants thought that replacing animal testing with advanced technology might be costly for governments. For him, this may cause economic and social problems in the country. Another participant thought that the production of medications is a very profitable business. So, for this participant, as scientists perform more experiments to invent medicines, they contribute to making higher profits as shown in the excerpts below:

This issue is related to economics and politics because the more they [scientists] do experiments, the more they get the money that's why they agree on animal testing (P11, Q4)

Science is related to economics because it takes a lot of money for the governments to get this new thing [medication], and they need to pay people to build it and to invent [medications] ... to buy it and put it in the stores ... buying more labs costs a lot of money. If there is a country that its economy is going down, they might not choose this path; they might get backlash from society. They might get pressured into doing it, and the country might lose a lot of money (P9, Q4).

Analysis of the questions of the fourth set of activities (Q4) showed a slight increase in the number of participants showing intermediary views on the relationship between science and economics. These participants described the relationship between science and economics and thought that people spend money on medications that result from animal testing, while scientists profit from inventing and selling medications, as shown in the excerpts below:

Humans might buy medicines that have been tested by animal testing (P8, Q4)

Some politicians support experiments on animals so that the government earns money out of the medication (P18, Q4)

Finally, analysis of the responses in the post-test indicated that only two participants (12.5%) did not respond to the question, and none of the participants had naïve views of the relationship of science and economics. However, 25% of the participants had intermediary views on this theme at the end of the study (Table 10). They viewed that decisions taken by the government to ban/reduce the production of any scientific products may lead to financial problems for scientists and the country, as shown in the excerpts below:

They are related because like if the government doesn't agree to decrease electromagnetic waves that will cause all the country, and the government lose money (P11, post)

The number of participants having informed views of the relationship between science and economics increased to 62.5% in the post-test (Table 10). The participants showed awareness that governments and people profit from selling scientific products such as technological devices and medicine. They also claimed that people, on the other hand, might be affected negatively financially as they spend money to buy expensive scientific products. Others mentioned that the negative effects of scientific products might lead to the closure of the factories and, in turn, to the increase in unemployment. Few participants thought that people's positions regarding a claim about a scientific issue might depend on their financial benefits. Some of the participants were able to explain how prices of certain products influence their consumption by the people. They claimed that people end up consuming more when the products are cheaper. These views are illustrated in the excerpts below:

They [scientists] are discovering things that are getting sold. When you are studying something like medicine, it is from the scientists creating this medicine to cure this type of sickness. The government may be testing it or checking it before they are selling it. It [science] is related to economics because it is like they are selling it [medicine]. It [medicine] might be very expensive or it might be very cheap. If it is expensive, not a lot of people could afford it, and if it is cheap, a lot of people can't afford it. If a lot of people can afford it, anyone could buy it. [we should] not to make it cheap enough so that people would buy it so much so that no one gets hurt or make mistakes in amounts [take medicine *in proper amounts]. Only specific places like hospitals, pharmacies or doctors should provide it so that they know that people don't take the wrong food like the golden rice accidentally. So, they will not really affect people who buy it just because it is cheap. Or else, they will eat it, and they will have negative effects. Fluoridated water and genetically modified food are sold in the supermarkets, and it should be stored in the doctors' workplaces and pharmacies and not in public places so that not anyone can go and buy. Doctors decide how much to take, how much to sell, and where to sell the cures for undiscovered diseases. Doctors need to give them something to buy the rice because people maybe couldn't differentiate between normal and golden rice. So, people don't eat it just to try it because this will definitely affect eye doctors (P8, post)*

People might support different stuff [opinions] to keep their jobs, and politicians might debate about different points of view, but they need to agree on a point to get scientific knowledge. Sometimes people support different ideas because they want money. They do not want to lose their jobs; they want to save their jobs. For example, dentists wouldn't support water fluoridation because if people would buy fluoridated water, then they will stop going to the dentist because people go to the dentist to get fluoride in their teeth. But if they get fluoridated water, they want to go to the dentist anymore so the dentist will not get the money as much, that's why he will not be supporting the idea of water fluoridation (P22, post)

Relationship between science and social organizations. Referring to Table 11, analysis of the responses in the pre-test showed that out of the sixteen participants, fifteen participants did not answer the question regarding the relationship of science and social organizations, while only one participant had naïve views regarding the relationship of science and social organizations. This participant stated that science and social organizations are not related to each other, as seen in the excerpt below:

Science is not related to social organizations (P15, pre)

However, analysis of the open-ended questions of the first, second, and third sets of activities (Q1, Q2, and Q3) in the context of climate change, water fluoridation, and electromagnetic wave pollution resulted in nearly similar classifications of participants into naïve, intermediary and informed.

Table 11

Frequency Distribution and Percentages of Students' Views of Relationship of Social Organization Theme

FRA Wheel Category	Relationship between Science and Social Organizations Totals *(N=16)*					
	Pre	Q1	Q2	Q3	Q4	Post
Naïve	1 (6.2 %)	1 (6.2 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)
Intermediary	0 (0 %)	5 (31.2 %)	5 (31.2 %)	6 (37.5 %)	2 (12.5 %)	4 (25 %)
Informed	0 (0 %)	8 (50 %)	9 (56.2 %)	8 (50 %)	12 (75 %)	10 (62.5 %)

1. Pre: Pre-test, Q1:1st set of activities, Q2: 2nd set of activities. Q3: 3rd set of activities, Q4: 4rt set of activities, Post: Post-test

2. The total number of participants may not be 16 as the participants, who did not respond to the question, were excluded.

At the end of the first set of activities (Q1), only two participants did not answer the questions. One participant was classified a naïve because he stated that science and social organization, such as NGOs and associations, are not related, as seen in the excerpt below:

Social organization cannot help in scientific issues because they are not related to each other (P16, Q1).

Analysis of the responses to the first set of activities (Q1) indicated that five participants (31.2%) developed intermediary views about the relationship between science and social organizations (Table 11). These participants' views showed that the relationship between science and social organizations is limited to contributing to environmental issues and raising awareness to convince people to support a specific cause, as seen in the following excerpts:

NGOs and associations help to recycle more and reduce the pollution of popular companies (P2, Q1)

Social organization raise awareness regarding human actions that harm the environment (P19, Q1)

They can convince the people and the government or politicians to care about our earth and try to convince other people to protect the earth and reduce pollution (P5, Q1)

They try to convince people about what they say is true. (P10, Q1)

Furthermore, after engaging in the first set of activities (Q1), half of the participants (50%) developed informed views regarding the relationship between science and social organizations (Table 11). These participants provided more than one informed view to relate science to social organizations. They claimed that NGOs organize campaigns regarding problems in the society to influence governments' and people's decisions or behavior, as well as raise awareness to find solutions to social problems as illustrated in the excerpts below:

> *They should talk to people about the negative effects of pollution and greenhouse gases when they do campaigns and projects to convince people to stop polluting the air (P20, Q1)*

> *They should spread awareness and do campaigns to stop pollution and to keep our climate safe. After they spread awareness, the people might think like we should not pollute so that negative effects won't happen. Factories will not produce greenhouse gases to pollute the air; people will start to think about it for a minute and start to realize that they are doing something wrong. Factories will put filters on the top of its air [exhausts], and there will be less pollution. Climate change will be solved, they will keep on spreading awareness to the government influencing and having a good impact on the government. (P14, Q1)*

> *They can convince the people and the government or politicians to care about our earth and try to convince other people to protect the earth and reduce pollution (P5, Q1)*

> *They organize it [campaigns] in order to convince every person about a certain issue, and this person may change his mind and he may he would take the decision (P15, Q1)*

Analysis of the responses of the open-ended questionnaires at the end of the second set of activities (Q2) showed that two participants did not respond to the questions about the relationship of science and social organizations, and none of the participants had naïve views regarding this theme (Table 11). Similar to the results of the analysis of the questions of Q1, five participants (31.2%) showed intermediary views claiming that social organizations collect information from scientific researches and use them as proof to convince governments regarding the negative effects of scientific innovations as shown in the excerpts below:

Some organizations can deliver messages regarding people's issues to the government (P18, Q2)

They can prove to the government that it [electromagnetic wave pollution] causes diseases (P11, Q2)

One participant mentioned those social organizations are capable of convincing governments to give a choice to the citizens through democratic practices such as voting as shown in the excerpt below:

They [social organizations] would convince society and the governments by not adding fluorine; their role is to convince everyone to have a choice. Let the people have a choice and let them vote to make water bottles without fluorine and water bottles with fluorine (P5, Q2)

At the end of the second set of activities (Q2), nine participants (56.2%) showed informed views about the relationship between science and social organizations (Table 11). A participant showed awareness about the existence of social and health organizations that support specific causes and human rights, as illustrated in the following excerpt:

> *There are social organizations that will decide. There is a social organization that is for dentists. For example, there are dental associations and others of this kind or UN related to people's health definitely contribute to the health of people (P8, Q2)*

Several participants claimed that social organizations raise awareness, organize campaigns, and work with the government to find solutions to pressing social issues. They work to give people the option of choosing the type of water they want to drink so that debates/protests regarding these issues do not take place, as seen in the excerpts below:

> *They can make water that is without fluoride. That way, the society will have options, and the politicians will not fight. Each person will have what they want because some people want fluoride and some people don't. So now they [people] have options to choose what they want to drink. They cooperate with them [social organizations] like they make ideas about what they want to do to the country and think of campaigns. They also like to work together for the society of the country; they work together to know what society needs and what should they do (P22, Q2)*

> *I think before they spread awareness about it, they should ask or share their ideas about fluorine. They should see the average of the people who accept fluorine bottles or not, then produce one company that produces water with*

fluorine that contains a certain amount of it and put a specific time for drinking it and spreading awareness about it (P19, Q2)

They [social organizations] can spread awareness to the government and campaigns about water fluoridation and inform the people about the water they are drinking. They can spread awareness and do campaigns to show to the government the negative and the positive effects of fluorine (P14, Q2)

At the end of the third set of activities (Q3), two participants did not respond to the question regarding the relationship between science and social organizations, and none of them had naïve views. On the other hand, six participants (37.5 %) showed intermediary views on the relationship between science and social organizations (Table 11). They mentioned that social organizations contribute to addressing environmental issues and raising awareness to convince people to support a certain cause, as seen in the following excerpts:

They raise awareness about the issue, so they say if you are not using it turn off the Wi-Fi not to get cancer or not get any other disease (P9, Q3)

They can raise awareness about the positive and negative effects of electromagnetic waves (P20, Q3)

Some organizations can spread information about electromagnetic wave pollution (P18, Q3)

One participant mentioned that social organization is capable of convincing governments to give a choice to the citizens through democratic practices such as voting as shown in the excerpts below:

They [social organizations] can advise the government to vote and see what people's choices are (P10, Q3)

At the end of the third set of activities (Q3), half of the participants (50%) had informed views on the relationship between science and social organizations (Table 11). These participants mentioned more than one role of social organizations in scientific issues. They claimed that NGOs organize campaigns to influence governments' and people's decisions or behavior, as well as raise awareness to find solutions to social problems. Social organizations report to the government about the negative effects of electromagnetic wave pollution and support their positions by evidence collected from experiments. They also report to the government the unethical actions against humans. These views are illustrated in the following excerpts:

They can prove to the government that electromagnetic wave do harm people. They can support their position by experiments and evidence, and the government will have no choice other than to decrease the electromagnetic waves in the country (P11, Q3)

Social Organizations can make awareness about the electromagnetic waves and their negative effects. They can raise awareness so that they will stop the creators or anybody from stopping making more phones all electromagnetic waves. They will tell the government to stop, and they share with them the ethical, that it is not ethical to harm people (P4, Q3)

Basically convincing as much as they can everyone like governments, society scientist… or maybe write articles and try to convince everyone to come up with a solution (P5, Q3)

Analysis of the answers to the questions in the fourth set of activities (Q4) showed that only one participant did not respond to the question on the relationship of science and social organizations, and none of the participants showed naïve views about this relationship. On the other hand, the number of participants classified as having intermediary views dropped to two participants (12.5 %) (Table 11). The responses of these participants related science to social organizations through influencing people's opinions and convincing them to support a certain cause or a view as seen in the excerpts below:

> *Social organizations raise awareness about animal testing to protect the animals (P12, Q4)*
>
> *They would let people support a certain view (P15, Q4)*

The answers to the questions of this set of activities indicated that the majority (75 %) of the participants had developed informed views of the relationship between science and social organizations (Table 11). In these answers, the responses of the participants did not differ much from the previously given informed views. However, it was notable that after engaging in the activities in the context of animal testing, some of the participants recognized the important role of the social organizations in protecting the rights of animals as shown in the excerpts below:

> *Obviously, they want to support animals. They try to convince the government, as I said, to develop technology and reduce animal testing. It's so sad how they are harming the animals and how it can lead to extinction, then they want to convince everyone to build based on evidence boxes 6 and 4. They are*

influencing the society to protest against the position of the government and to really convince everyone that animal testing is really not ethical (P5, Q4)

I think they should debate with all the government and take one decision and stop animal testing (P19, Q4)

They spread awareness and write articles about it to inform the government about the human activities and their negative effects on the animals and should spread awareness and do campaigns to help the animals they should convince all the people to support model B as said in the MEL diagram like we should not harm animals. the ones who love animals should support model B to try to convince the highest amount of people to support model B to convince the scientists that model B is better than model A… they are trying to decrease the amount of animal testing because they don't want animals to die or to get harmed … (P14, Q4)

These participants also mentioned that social organizations convince people to take a certain position by raising awareness and organizing campaigns. They thought also that social organizations organize protests to demand certain changes from the government and convince people to take part in them. Few participants thought that social organizations promote organizing voting to make decisions based on what the majority of the citizens want and to let people feel that their opinions are respected by the government as shown in the excerpts below:

To support one idea and try to convince everyone about their opinion by evidence and research. They would convince the society will protest to convince *the government economic wise to reduce the carbon dioxide for example (P5, post)*

They [social organizations] make people's opinions protected by society and make things how people wanted to be like through voting the people will vote, and they will see the highest score people will know that they are deserving this and the society is following, and they will feel like their opinion in the place where they live is really protected (P8, post)

Analysis of the responses of the post-test showed that two participants did not respond to the question, while four showed intermediary views when relating social organizations to science (Table 11). These participants claimed that the role of social organizations is to influence people's decisions by raising awareness about a certain issue, as shown in the excerpts below:

[Social organizations] change people's mind to think on the other hand (P10, post)

Social organizations raise awareness about a certain topic (P12, post)

Social organizations influence people's decisions (P15, post)

Furthermore, analysis of the responses to the question on the relationship of social organizations and science showed that more than half of the participants (62.5 %) were capable of providing informed views on the relationship between social organizations and science (Table 11). These participants elaborated on their responses regarding the relations between science and social organizations in several ways. They provided detailed examples of how social organizations influence the decisions taken by the government by reporting people's concerns to the government. They thought that, in this way, social organizations try to help people to find solutions to the adverse effects of scientific innovations, as shown in the excerpts below:

> *They [social organizations] tell the government about all the people's concerns and problems related to politics, economics, and science. Social organizations tell the government all the complaints and their [people's] problems so that they help them so that the government tries to find out solutions to help them. Maybe they will encourage the government to shut down or improve something if they [people] have something against it. Maybe they [governments] don't believe it and say that it [electromagnetic wave] is fine so that people continue to buy them so that they don't lose money… (P2, post)*

> *The social organization also helps scientists in the scientific issue. They can raise awareness for everyone or any issue and help even the government and the people. They tried to change the negative to positive things (4, post)*

> *[Social Organizations] show them [people and the government] how they [scientists] worked … to show them how they found that this is the way to protect blindness, so they will show them how they work. They [scientists] show them how they found the data and the evidence. They of course work with the society so that they help the society to show the products and how they are working so that the society will be convinced by the scientists and the government (P8, post)*

> *They [social organizations] spread awareness and help the government. They also might make things to solve problems. They can help solve the problem; for example, for the electromagnetic waves, they can come up with ideas with*

machines that can help. They can spread awareness. They can talk to the people, and maybe those people are good at making machines so they can work together with the society to make the machines. They try to change the opinions of the people. For example, animal testing a lot of people are making websites and spreading awareness for people. Some are doing a big sale to collect money for the animals like it is fundraising for animal testing. They were trying to spread awareness, so people stop thinking badly. For example, it is kind of like in our class we were trying to convince P9 that animal testing is not really good for the animals, and after eating all the opinions, he changed his opinion. This is what social organizations try to do. They tried to change other people's opinions. They tried to help the society to solve the problem; for example, for animal testing, they might tell people that they should test on samples of humans and not the whole body. That will be more accurate and will not harm anyone. So they will give ideas to solve the problems so that everyone will be satisfied with the solution (P22, post)

Ethical issues in science. Referring to Table 12, analysis of the responses in the pre-test and the open-ended questions of the first set of activities (Q1) in the context of climate change indicated that none of the participants responded to the question about the relationship of science and ethical issues. However, after engaging in the second set of activities (Q2), the number of participants who did not respond to the question of this theme sharply dropped from sixteen participants (100%) to one participant (6.2%). Moreover, none of the participants had naïve views of ethical issues in science. The majority of the participants (75 %) showed intermediary views regarding the relationship between ethics and science. These participants considered unethical to force people to intake excessive fluorine without being aware of their intake, as seen in the following excerpts:

> *It is not ethical to give people medication without asking or without them feeling because fluorine is like a medication to people, but it is a harmful one, so it is not ethical (P4, Q2)*

> *It is not ethical since we are forcing people to take medication without knowing and this may cause them health problems (P5, Q2)*

> *Yes, because you are forcing people to take medicine like medicine in water and maybe some people might not know they are doing this and think it is just water, but it is water with fluorine, and some people are against fluorine because they support model B (P9, Q2)*

Table 12

Frequency Distribution and Percentages of Students' Views of Ethical Issues in Science Themes throughout the Study

FRA Wheel Category	Ethical Issues in Science Totals *(N=16)*					
	Pre	Q1	Q2	Q3	Q4	Post
Naïve	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0%)
Intermediary	0 (0 %)	0 (0 %)	12 (75 %)	11 (68.7%)	3 (18.5 %)	5 (31.2%)
Informed	0 (0 %)	0 (0 %)	3 (18.7 %)	5 (31.2%)	9 (56.2%)	0 (0%)

1. Pre: Pre-test, Q1:1st set of activities, Q2: 2nd set of activities. Q3: 3rd set of activities, Q4: 4rt set of activities, Post: Post-test
2. The total number of participants may not be 16 as the participants, who did not respond to the question, were excluded.

Moreover, at the end of the second set of activities (Q2), the number of participants having informed views increased to 18.7% (Table 12). Participants having informed views claimed that imposing on people to drink fluoridated water is unethical. Besides, these participants highlighted the importance of giving choices to people to drink any water they desire, as shown in the excerpts below:

> *It is not ethical to put fluoride in water since it is forcing society to drink it. It is more ethical to give the people a variety; the people that want fluoride to get it and people that don't (P22, Q2)*

> *It is not ethical since people don't want to drink it so. Basically, they are forced by society, so if dentists want to remove a cavity they can ask if they want to drink the water or they remove it (P8, Q2)*

One participant mentioned the importance of controlling the dosage of fluoride in the water bottles and prescribing a suitable time for drinking fluoridated water. The government has to make sure that people are not forced to intake very high amounts of fluorine, as shown in the excerpt below:

> *Water that contains fluorine is being forced to be drunk by the society. I think all governments should produce bottles that contain a certain amount of fluorine that has a specific time to drink (P19, Q2)*

These different views did not seem to change much in the answers to the questions in the third set of activities (Q3) in the contexts of electromagnetic wave pollution. None of the participants showed naïve views regarding ethical issues in science. The number of participants having intermediary views was eleven (68.7 %) (Table 12). These participants considered that exposing people to electromagnetic waves, even though they try to prevent themselves from this exposure, is unethical as illustrated in the following excerpts:

People are being forced to stay next electromagnetic waves. There are electronic devices around us. If you keep yours away, there are still the others who are around you (P2, Q3).

Maybe some people are not in contact with electromagnetic waves, and they don't want to get in contact. But the neighbors and anybody next to them are using iPhone even if they don't want to get in contact, not to be caused by diseases. It is not ethical for the other people, or anyone let the other person get in contact with the electromagnetic wave (P4, Q3)

Because you don't have a choice not to be receiving electromagnetic waves (P12, Q3)

However, at the end of the third set of activities (Q3), the number of participants having informed views of ethical issues in science increased to 31.2% (Table 12). These participants elaborated their answers, suggesting that it is unethical for people to cause harm to others, as shown in the excerpts below:

We are making technology and still don't know it that it does cause cancer, and we are still making the technology, so we are giving the people cancer that they don't deserve. Like there are a lot of people who get cancer by doing nothing. They don't have other diseases. They get cancer. People will use it [devices that emit electromagnetic waves], and it might also come to me, it will also affect me. Like because of neighbors next to us, if I open the settings of my phone of the Wi-Fi, it says that there is much other Wi-Fi even if I shut my Wi-Fi (P9, Q3)

People are obliged to sit in a place with electromagnetic waves. Maybe they don't want to. I think people should not be exposed to electromagnetic waves because if they read Model A, they will be convinced that it does cause cancer. So, they will not like to be exposed to electromagnetic waves, and it is obligatory for the people to stay beside it (P10, Q3)

At the end of the fourth set of activities (Q4) in the context of animal testing, none of the participants were classified as having naïve views of ethical issues in science (Table 12). While four did not respond to the question. On the other hand, the number of participants having intermediary views dropped sharply from eleven (68.7 %) to three participants (18.5 %). For these participants, performing animal testing and harming them for humans' benefits are not ethical as shown in the excerpts below:

It is not ethical to harm animals for the sake of experimentation (P20, Q4)

Animals are being killed because of tests and experiments (P18, Q4)

After engaging in the fourth set of activities (Q4), the number of participants having informed views of ethical issues in science increased to nine participants (56.2%) (Table 12). The majority of these participants came up with similar informed views. They considered animal testing ethically unacceptable because humans exploit the animals for their benefits without showing empathy. They also thought that classifying humans as more important living things than animals is wrong. They appreciated the role of animals in people’s lives and the ecosystem. They claimed that humans do not have the right to hurting animals, as they also have feelings similar to humans.

The people who are testing animals and seeing how much they are suffering and that they don't care. When people are testing on animals, the animals are forced to be tested on like they cannot choose (P22, Q4)

The ethical issue is that we don't have the right to harm the animals because they are living species like us. So they should take samples of us or even volunteers instead of harming the animals because it is not our right to harm the animals (P14, Q4)

As P9 said, we usually tested on animals and not on humans because humans have a bigger future and may change something in life … animals don't have a choice to be tested or not (P12, Q4)

It is not morally right to do animal testing because animals also have a role in life. Animal testing causes a lot killing animals because they might be killing animals when testing because a lot of drugs and medicine sometimes might have something wrong in it might cause fatal accidents and animals have different reactions than humans this might also mean that humans might die (P9, Q4)

It is very wrong to do that [Animal Testing]. Animals are like humans. They [animals] also have feelings that would hurt them. It is a really bad thing to the animals, but at least we need to be sure that the thing that we are using the animal for or harming this animal (P8, Q4)

Finally, the analysis of the responses of the post-test did not show consistency with those of the previous open-ended questionnaires. In the post-test, the majority of the participants (81.2%) did not respond to the question, while none of the participants had informed views of ethical issues in science. Only five participants (31.2 %) showed intermediary views of ethical issues in science (Table 12). These participants gave examples of the ethical issues, which were discussed in the previous sets of activities in the contexts of water fluoridation, electromagnetic wave pollution, and animal testing. Two of the participants showed how imposing people to drink fluoridated water as an unethical act related to science, while the other two discussed how harming animals is unethical, as shown in the excerpts below:

> *Because society might be doing something against their will example drinking water fluoridation (P9, post)*
>
> *We don't force the society to take the medication and not knowing the side effects (P5, post)*
>
> *It is not ethical to harm animals for testing medications (P16, post)*

Analysis of changes in NOS views by participants.

The following section presents the analysis of the changes in the NOS views of the participants throughout this research study, starting from the pre-test to the four sets of activities (Q1, Q2, Q3, and Q4) and the post-test. Additionally, this analysis compares each participant's NOS views on each of the ten themes throughout the intervention to study the development of their NOS views in the contexts of Climate Change, Water Fluoridation, Electromagnetic Wave Pollution, and Animal Testing. Additionally, the participants were randomly selected to analyze their responses in detail and prepare summary profiles for each.

Tentative nature of scientific knowledge. As shown in Table 3, analysis of the responses of the pre-test indicated that, out of sixteen participants, four participants (25% %) had naïve views of the tentative nature of scientific knowledge. One participant did not respond to the question that aimed to assess participants' views of the tentative nature of scientific knowledge. However, the number of participants having naïve views of the tentative nature of scientific knowledge decreased to 0% in the posttest (Table 3). In the post-test, all of the participants responded to the question about the tentative nature of scientific knowledge, but none of the participants had naïve views. As nearly half (56.2%) of the participants had intermediary views of the tentative nature of scientific knowledge in the pre-test, less number of participants (37.5%) showed intermediary views in the post-test. Finally, analysis of the results of the pre-test indicated that only two participants (12.5%) had informed views of the tentative nature of scientific knowledge, while the number of these participants significantly increased to 62.5 % in the post-test (Table 3).

Analysis of the responses to the question about the tentative nature of scientific knowledge showed that after engaging in information credibility evaluation activities and reflective discussions, participants were able to develop more informed views of the tentativeness of scientific knowledge. Below please find the detailed analysis of responses of three randomly selected participants to the question that aimed to assess their views on the tentative nature of scientific knowledge.

Participant 5. Before engaging in the four sets of activities, analysis of the responses in the pre-test indicated that views of P5 regarding the tentative nature of scientific knowledge were naïve. P5 thought that scientific knowledge is unchanged as the earth has remained unchanged for thousands of years, as shown in the excerpt below:

It will not change because everything that is on Earth from thousands of years ago till now is still the same. So why would it change? (P5, pre)

After engaging in the first set of activities (Q1) in the context of climate change, P5 shifted his views and considered that scientific knowledge changes because scientists get convinced of alternative opinions when the opponents show relevant and tangible evidence as shown in the excerpt below:

If something is happening and there were evidence and data and research, then they [scientists] would probably change. [Scientific knowledge changes] If they show a video or something that will let them believe, they show them in reality, and they see it in their own eyes. But not until now we don't have [data, evidence…]. So, they don't change my opinion (P5, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P5 developed informed views about how scientists might discover new information and develop or make changes in the currently available knowledge as shown in the excerpt below:

Change in scientific knowledge is based on how they [scientists] discover new things in the future or present and how we develop it [scientific knowledge] more ... (P5, Q2)

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P5 was able to elaborate more informed views regarding the tentative nature of scientific knowledge. P5 claimed that more detailed information might be added to the current knowledge and might lead to changes in scientific knowledge. He also claimed that changes in evidence might lead to changes in the decisions that people make regarding a specific issue. P5 elaborated his answers by mentioning the role of technology, which constantly improves, in making modifications in scientific knowledge. He stated that the availability of more advanced technologies in the future might lead to minor changes in some of the scientific knowledge. At this stage, P5 was aware that not all scientific knowledge changes, as shown in the excerpt below:

> *If the knowledge we have now needs more information and at some points, we need to change, then they will probably change it [scientific knowledge]. If, after ten years, we develop cancer [because of electromagnetic wave pollution], they might be changes in opinions to model B. If our technologies are advanced in the future, and if we go deeper in objects, then we would probably change. But for example, gravity will not change in the future because from thousands of years it is the same and there are major things that we keep the same but minor things we may change it if we advance the technology. In the past and present times, technology has changed and improved, and it is constantly improving. So, electromagnetic waves developed more because it turned out to be we need the radiation for it [technology] to work (P5, Q3)*

In the context of animal testing, after the last set of activities (Q4), P5 gave one informed view of the tentative nature of scientific knowledge; therefore, his views were classified as an intermediary. P5 thought that human activities might lead to changes in the globe, which, in return, lead to changes in scientific knowledge, as shown in the excerpt below:

Maybe in the future of the earth, it [scientific knowledge] can change because of changes in human activity (P5, Q4)

In the post-test, P5 provided several informed views of the tentative nature of scientific knowledge. He claimed that scientific knowledge changes as scientists make discoveries and suggest new theories with the help of advanced technology. He mentioned that research methodologies might be changed and replaced by technology, depending on future developments. He explained that scientists might falsify previous knowledge or add on it based on new evidence. When scientists find stronger evidence, engage in argumentation, and convince other scientists, they change their views and improve their knowledge. P5 understood that some of the scientific knowledge does not change because scientists have studied them thoroughly and proven their accuracy. Others that are not yet profoundly studied might change in the future with further discoveries, as illustrated in the excerpt below:

Yes, because of scientific knowledge changes as we discover new things and find out that a discovery, which was previously theorized, was wrong and is something else. Anything could happen with scientific knowledge. Maybe in the future, our developed technology could discover a lot of things that would change our current scientific knowledge. For example, in the animal testing issue, the technology we have now could be more developed in the future, which could prevent performing animal testing. So, depending on how we build our future and how we build our technology, scientific knowledge can change or remain as it is. It [scientific knowledge] may change when scientists write supporting articles or models with strong evidence, convince other people and change other people's scientific knowledge, improve their scientific knowledge, *and argue with scientists about certain models that have different points of view. The laws and the unproven facts that we have in our textbooks may change. Let's make the gravity; for example, it cannot change in the future unless we change the Earth with something. It cannot change, while other topics that we didn't discover knowledge deep in the subject may change in the future the scientific knowledge (P5, post)*

Participant 8. Analysis of the pretest showed that P8 already had intermediary views of the tentative nature of scientific knowledge. Before engaging in the activities, P8 considered that scientific knowledge keeps on changing. She mentioned that views regarding specific scientific knowledge might change as people do not question the hazards of scientific products, as seen in the excerpt below:

Scientific knowledge changes as people accept to use illegal or untested scientific products such as GMF (P8, pre)

After engaging in the first set of activities (Q1) in the context of climate change, P8 was already able to develop informed views of the tentative nature of scientific knowledge. She considered that scientific knowledge changes as scientists make different observations, recognize negative influences, and believe in alternative explanations, as shown in the excerpt below:

Depending on what we see anywhere we might see people do harmful things and start to believe that these are the harmful things that are causing climate change (P8, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P8 linked the tentative nature of scientific knowledge to the process of updating the currently available scientific knowledge through finding more evidence and data as shown in the excerpt below:

> *We need to know what is happening now because before they didn't discover a lot of things. Before they only discovered the positive things about water fluoridation and now they discovered the positive and the negative effects (P3, Q2)*

Engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution allowed P8 to provide more than one informed view to explain the tentative nature of scientific knowledge. P8 was able to realize that scientific knowledge may change with the help of advanced technology because she thought that technology allows for discovering more details. Discovering detailed information may help scientists to identify previous mistakes that are hard to find without technology. Moreover, P8 became aware that changes in scientific knowledge occur because scientists may come up with new evidence, link it to previously discovered evidence, and suggest different claims after engaging in discussions or debates. Additionally, P8 thought that as more technological devices are created, people would be exposed to more electromagnetic waves. Changes in such factors may result in contradictory evidence and lead to a change in scientific knowledge, as shown in the excerpt below:

> *First, they will see the mistakes they have done before so that they correct things and combine all the evidence and the proof. A scientist might come up with a new thing different than Model A and B. they might find model C. They can work together, debate and tell each other what they have done and share the proofs they have so that both of them discuss about it and see what would work in the*

future technology will increase a lot, and everything will be technology like phones, and everything and electromagnetic waves will increase more, and maybe more diseases will happen even if they found the cure (P8, Q3)

After engaging in the fourth set of activities (Q4) in the context of animal testing, P8 showed informed views. She restated the role of technology in changing scientific knowledge. She mentioned that advanced technology causes changes in scientific practices and experimental setups, as seen in the excerpt below:

The future of technology will evolve, and it will be more advanced. So, scientists will use technology to test on and not on animals or humans. So, definitely, some scientists will change their opinion (P8, Q4)

Finally, P8 showed informed views of the tentative nature of scientific knowledge in the post-test. She mentioned that scientific information changes because scientists might add new information to the currently existing information after performing tests on people/animals and suggesting certain advancements. For this reason, she thought that scientists repeat studies to ensure the validity of the data. P8 also mentioned that science makes the world a better place. Consequently, scientific knowledge goes through continuous improvements. That is why P8 claimed that information printed in the textbooks change, as illustrated in the excerpt below:

Yes, because science is what makes our world better. The advancements might be made. For example, the amount [of genetically modified food] maybe they change it or add new information to it. They [scientists] will definitely test on people or animals so that they can make sure that their calculations and the researches are correct. Or else, this genetically modified food will be canceled, *or maybe they acknowledge that it cures blindness. Technology will evolve, and things will change, and anything will happen. So, definitely, books will change, and the magazines and stuff like this will change (P8, post)*

Participant 22. Analysis of the responses to the pre-test showed that P22 had naïve views regarding the tentative nature of scientific knowledge. She considered that scientific knowledge is not subject to change because it is reliable and consistent, as shown in the excerpt below:

Scientific knowledge will not change because it is something consistent (P22, pre)

After engaging in the first set of activities (Q1) in the context of climate change, P22 showed intermediary views regarding the tentative nature of scientific knowledge. She claimed that scientific knowledge is subject to change because discoveries might update or modify previously developed knowledge, as seen in the excerpt below:

Maybe they [scientists] discovered something in the past, but now it is developed and changed into something else (P22, Q1).

Engaging in the second set of activates (Q2) in the context of water fluoridation helped P22 to develop informed views of the tentative nature of scientific knowledge. P22 claimed that scientific knowledge changes because scientists make discoveries and find more data and evidence. She thought that the current and new evidence might disprove the evidence collected earlier. Also, she considered that since scientists have the opportunity of sharing information through the internet, they might give a more detailed explanation about the advantages and disadvantages of fluoridation, and lead to changes in knowledge, as shown in the excerpt below:

Some people, when they did experiments before, said that it [fluoridated water] is good, but more lately, they said it is not good. So, scientists should be following the more current one, not the one that was a long time ago. Maybe a long time ago they thought that water fluoridation is something really good. Over the years, when they do more research and put new stuff on the internet, it might add more information, and it will tell why it is good and why it is bad [more detailed explanation] maybe find out that it has a bad effect (P22, Q2)

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P22 provided informed views of the tentative nature of scientific knowledge as well. She focused on the critical role of evidence in the creation of modified knowledge. She claimed that scientific knowledge changes when more robust, accurate, and current evidence is discovered about a particular claim. Besides, she stated that finding evidence might take a long time. Therefore, change in knowledge may not be frequent, as shown in the excerpt below:

It [changes in scientific knowledge] depends if they got more accurate and current info for [model] (A). So, maybe after ten years if the cancer was not promoting and they had a proof for it, then I might support model B (P22, Q3)

Analysis of the responses of the fourth set of activities (Q4) in the context of animal testing showed that P22 had informed views. P22 thought that changes in scientific knowledge depend on the accuracy of evidence that is provided as a result of discoveries, as shown in the excerpt below:

I am not sure it depends on how new discoveries find out accurate evidence (P22, Q4)

Finally, responses to the posttest show that P2 demonstrated several informed views regarding the tentative nature of scientific knowledge. She showed awareness that specific scientific knowledge is subject to change; however, not all of this knowledge. She thought that a subset of scientific knowledge is already confirmed. However, in some cases, scientific knowledge changes when scientists discover the positive or negative effects of scientific products. It also varies because scientists start to use more advanced technology, as shown in the excerpt below:

> *Maybe they [scientists] did more research and saw the positive and negative effects of them [scientific products] because the technology gets more advanced and they do more research … not everything [changes] because some things can't change. For example, the density of water can't change, but for example, when Pluto was once considered as a planet but now they changed, and they think that it is not a planet. So, if we look in the old textbooks, we can see that it is the still a planet, but we should look at the more current ones because we can see current information and accurate because it is more current (P22, post)*

The tentativeness of personal explanations in science. As shown in Table 4, analysis of the responses to the pretest showed that seven participants (43%) had naïve views of the tentativeness of personal explanations in science. In the posttest, the number of participants having naïve views dropped to zero. None of the participants had naïve views of the tentativeness of personal explanations in science after engaging in four sets of activities. On the other hand, in the pretest, none of the participants showed informed views of the tentativeness of personal explanations in science, while after engaging in the four sets of activities, six participants (37.5%) were able to show informed views of the tentativeness of personal explanations in science (Table 4). In addition, the number of participants having intermediary views in the pretest (43%) increased to 62.5% in the posttest (Table 4). Below please find the detailed analysis of responses of three randomly selected participants to the question that aimed to assess their views on the tentativeness of personal explanations in science.

Participant 5. Analysis of responses to the pretest showed that P5 had intermediary views regarding the tentativeness of personal explanations in science. He considered that people's opinions change if scientists perform tests and find more valid information, as shown in the excerpt below:

> *No, my decision would maybe change if they got everything right and tested everything (P5, pre)*

After engaging in the first set of activities (Q1) in the context of climate change, P5 continued providing intermediary views of the tentativeness of personal explanations in science. He thought that scientists change their mind depending on the evidence, research, and experiments that are available and make data more logical, as shown in the excerpt below:

> *When sufficient data and evidence is not provided regarding the opposing view, individuals do not change their minds. There isn't enough data or evidence or proof because maybe scientists have not revealed their results yet. If there wasn't enough data, then why would they change their minds? (P5, Q1)*

Engaging in the second set of activities (Q2) in the context of water fluoridation resulted in informed views of the tentativeness of personal explanations in science. P5 claimed that changing views regarding specific issues might be possible if enough convincing and robust evidence supporting the alternative view becomes available. He elaborated, mentioning that scientists write articles to represent the evidence and convince other people to change their views, as shown in the excerpt below:

> *I will most probably not change. But if they had convincing and strong evidence on model B…, let's say evidence 8 ... I might change. Scientists write articles to convince other people (P5, Q2).*

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P5 elaborated his responses and provided more than one informed view regarding the tentativeness of personal explanations in science. At this stage, P5 highlighted the importance of technology and evidence in influencing and changing people's explanations. He thought that people change their opinions when scientists add more detailed information on the current information, as shown in the excerpt below:

> *If, after ten years, we develop cancer, I may change my opinion to model B. If the knowledge we have now needs more info or there are some points we need to change, then they will probably change it. If our technologies are advanced in the future and if we go deeper in objects, then we would probably change (P5, Q3)*

In the context of animal testing, after engaging in the fourth set of activities (Q4), P5 showed intermediary views about the tentativeness of personal explanations. He claimed that changes in explanations and opinions occur as specific scientific procedures or practices change, as shown in the excerpt below:

> *People change their positions when changes in the animal testing procedures take place (P5, Q4)*

Finally, in the posttest, P5 showed informed views about the tentativeness of personal explanations. He considered that people change positions regarding a scientific issue when newly discovered evidence is strong enough to show the negative effects of a scientific product and to convince them to change viewpoints as illustrated in the excerpt below:

> *According to scientific knowledge, anything could happen with this issue. So, if, in the future, we discover that genetically modified rice is not good to sell, I will most likely change my mind. [I will change my mind] when there is research being done to show me that the evidence about the research they have done is strong enough to convince me like it can cause side effects on people (P5, post)*

Participant 8. Analysis of the responses of the pretest revealed that P8 has intermediary views of the tentativeness of personal explanations in science before engaging in the activities. She thought that people change their minds about the production of scientific products when these products improve and become more useful with time. That is when the negative effects of the products are reduced, and the positive effects are clarified, people might shift their opinions about the products, as shown in the excerpt below:

> *I might change my mind because it [genetically modified food] may be a bit useful. They [scientists] will look at the negative and the positive effects, and they will try to change the negative effects… (P8, pre)*

After engaging in the first set of activities (Q1) in the context of climate change, P8 already had informed views about the tentativeness of personal explanations. P8 attributed changes in opinions and explanations to new information that is developed because of continuous experimentations, which allows people to support a certain view and change their opinions. Moreover, she mentioned that people try to validate their opinion to convince others with their views. As people get convinced, they make changes in their explanations, as seen in the excerpt below:

> *I think that scientists change their minds because they continue doing calculations and experiments. They won't stop. They will still be against the other scientists, or maybe they will find something that may be like other scientists will help them to show them that their opinion is right. So, what they found and what they did will help them to have one opinion, and that will make better for everyone (P8, Q1)*

After engaging in the second set of activities (Q2) in the context of water fluoridation, P8 showed informed views about how strong evidence verifies or falsifies a certain claim and accordingly causes a change in people's opinions. She explained that as scientists identify negative or positive effects of a scientific product, people might change their opinions regarding the product, as shown in the excerpt below:

> *Changing a point of view regarding a claim is possible only when strong evidence that proves that the alternative claim is right is provided. I might change my opinion if it is fully tested after scientists will remove diseases from it (P8, Q2)*

P5 continued demonstrating informed views of the tentativeness of personal explanations in science after engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution. She claimed that the strength of the evidence supporting a certain position might convince people with alternative views and cause changes in their opinions. Moreover, she elaborated that technological innovations might allow the discovery of certain details about new information. Adding the details to the currently accepted knowledge might influence people's explanations regarding any issue. She elaborated by mentioning that strong evidence might falsify previous information or find the benefits of scientific products. She also thought that certain factors change in society and lead to adjustments in personal explanations, as shown in the excerpt below:

> *Changing positions regarding an issue occur when convincing evidence supporting the opposing claim is provided. First, they will see the mistakes they have done before so that they correct things so that they combine all the evidence and the proof they have like both scientists and come up with a new thing different than Model A and B, and might find a model C. They can work together and debate. They tell each other what they have found, and they discuss it. If scientists discover new things about model A and try to cure it, I might be a bit with Model B. For example, if they go back to what they have done, they might find something that they did not realize before, and so they can connect dots. Anything related to it, they need to consider it. In the future technology will increase a lot and everything will be technology like phones, and everything and electromagnetic waves will increase more, and maybe more diseases will happen even if they found the cure like if they found a machine or found a cure (P22, Q3)*

After engaging in the fourth set of activities (Q4) in the context of animal testing, P8 continued showing informed views regarding the tentativeness of personal explanations in science. She claimed that animal testing might be replaced by advanced technology. This might allow scientists to perform more experiments and to become surer of their claims. She thought that scientists might change their explanations as they collect more detailed information. She also considered that people change their opinions/decisions as they enter into discussion with others, listen to alternative ideas, and get convinced by it. She exemplified how one of her classmates changed his mind regarding animal testing while engaging in the reflective discussions, as shown in the excerpt below:

> *Yes. They will definitely change their opinion because the future of the technology will evolve, and it will be more advanced so scientists will use technology to test on and not on animals or humans. So, definitely, some scientists will change their opinion. During the discussion, P9 changed his decision. Maybe he saw that how the other people's opinion is convincing to him, and that is correct that model B is more supportive than model A. Maybe he saw that his opinion turned out to be wrong or he is thinking. He didn't think wisely before answering model A or model B. So; he thought that model B is better than Model A like my friends who are telling me that it is better like solutions like the technology or trying to use it in a good way (P8, Q4)*

Analysis of the post-test revealed that P8 showed informed views of the tentativeness of personal explanations in science. She claimed that people might change their opinions when scientists perform experiments with advanced technologies and discover details. Yet, she mentioned that technology might not provide fully secure data. The newly discovered information might be convincing, and accordingly, people might change their minds. Besides, she considered that people might change their opinions regarding the production of a scientific product, like genetically modified food, if scientists improve the product and reduce its negative effects. She mentioned that the mindset of people is developed according to scientific discoveries, as shown in the excerpt below:

> *Yes. I might since the future will be more advanced technology, and at the same time, we cannot really trust technology. So, I might change my mind depending on what convinces me. For example, if they removed the negative effects and turned them into positive effects. Maybe it's my mindset. How my opinions will change depends on what scientists will discover about genetically modified food (P8, Post)*

Participant 22. Analysis of the pretest showed that P22 had naïve views regarding the tentativeness of personal explanations. She considered that changing position regarding the consumption of scientific products, such as genetically modified food, is not possible because they are unhealthy, as shown in the excerpt below:

> *I don't think I will change my decision since GMF [genetically modified food] is not healthy at all (P22, pre)*

After engaging in the first set of activities (Q1) in the context of climate change, P22 developed intermediary views of the tentativeness of personal explanations in science. She understood the role of strong evidence in changing people's opinions and explanations. She inferred that the validity of information lets people support a certain position, as seen in the excerpt below:

> *I don't know. If the evidence for model B is stronger I might change my point of view, but model A sounds more valid (P22, Q1)*

After engaging in the second set of activities (Q2) in the context of water fluoridation, P22 also showed intermediary views of how personal explanations may change in scientific contexts. She claimed the possibility of changing positions about strong evidence that might change the way people think, as seen in the excerpt below:

For example, if model B has stronger evidence but when model A find stronger evidence, people will change their minds (P22, Q2)

Engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution allowed P22 to develop informed views about the tentativeness of personal explanations in science. She considered that scientists do change their minds upon finding stronger and more current evidence that supports an alternative position. However, she elaborated her answer by mentioning that changes in positions or opinions may take time as collecting evidence to support a claim might be a time-consuming process. She indicated that to check if electromagnetic waves cause cancer, scientists need to wait for years to collect that data as seen in the excerpt below:

It depends on the evidence. If evidence for model B becomes stronger and more current, I will support model B. Also, in evidence 8, it says that looking at trends over the last 20 30 years, we don't see an increase in cancer, but they don't know if it takes cancer ten years to promote. So maybe after ten years, if the cancer was not developing and they had a proof for it then I might support model B (P22, Q3)

Analysis of the questions in the fourth set of activities (Q4) in the context of animal testing showed that P22 had informed views of the tentativeness of personal explanations in science. She stated that scientists change their viewpoints when another viewpoint convinces them in case more relevant and accurate evidence is available. She thought that some scientists change their minds only if the issue does not contradict their values and principles. P22 illustrated how P9 changed his position in class after engaging in reflective discussions about animal testing, as illustrated in the excerpt below:

> *Maybe it depends on the more correct evidence. But I don't think I will change because for me it is not ok to test on animals. He (P9) got convinced of other people's opinions and changed his opinion… a long time ago maybe the discoveries weren't exact, they were trying on animals. New stuff will happen to the animals now because they made new discoveries so that they will know more. The test will be on humans, and the medicines are for humans, so it is more accurate (P22, Q4)*

In the posttest, P22 also showed informed views of the tentativeness of personal explanations in science. She considered that people might change their positions, depending on the availability of stronger and more convincing evidence. Also, she claimed that positions change depending on how much other people succeed in convincing others with their opinion. She exemplified again how P9 changed his position as he got convinced with the opinions of others during the reflective discussions, as shown in the excerpt below:

> *It depends if the evidence is more convincing or not. They can change their opinion because, for example, one of my classmates, when we were talking about animal testing, in the beginning, he was supporting model A, which said that it was ok [to do animal testing]. After he listened to the opinions of his*

friends, he realized that it wasn't ok and he changed his mind. So, it depends on other people's opinions and how do you get influenced by those opinions and how do they affect you because you understand more about the topic. If you understand more about the different points of views, you will be able to make a decision (P22, post)

Validity of information. Analysis of the responses of the pre-test that assessed participants' understanding of the validity of information indicated the majority of the participants (75%) had intermediary views (Table 5). None of the participants showed naïve or informed views in the pretest because four participants (25%) did not respond to the questions about the validity of the information. Analysis of the responses in the posttest showed that the number of participants having intermediary views of the validity of information (75%) did not vary after engaging in four sets of activities. However, the rest of the participants (25%) developed informed views (Table 5). Below please find the detailed analysis of responses of three randomly selected participants to the question that aimed to assess their views regarding the validity of the information.

Participant 5. Analysis of responses of the pretest indicated that P5 had intermediary views regarding the validity of the information. He realized the importance of evidence for supporting a particular claim. He considered that knowing more about a specific claim is necessary to ensure the validity of information, as shown in the excerpt below:

I would like to know if there are studying and researching for evidence about vegetables and fruits in medicine and not modifying vegetables and fruits (P5, pre)

After engaging in the first set of activates (Q1) in the context of climate change, he also showed intermediary views and mentioned the necessity of finding current evidence to make sure that the data is valid as shown in the excerpt below:

Evidence has to be current (P5, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P5 developed informed views of the validity of the information. He focused on the importance of the quantity and the strength of evidence. He considered that when a claim is supported with strong evidence, it becomes a more valid claim, as shown in the excerpt below:

What makes a data valid is the amount of evidence you have and how strong it supports the model (P5, Q2)

After engaging in the third set of activities (Q3) in the context of electromagnetic waves pollution, P5 showed informed views of the validity of information similar to those in the previous set of activities. He claimed that the validity of information depends on the number and the strength of evidence provided to supports the information, as shown in the excerpt below:

How strong is the evidence and how much data you have to support it [a claim] strongly…? (P5, Q3)

After engaging in the fourth set of activities (Q4) in the context of animal testing, P5 had informed views of the validity of the information. He recognized the importance of the currency of evidence along with its quantity and strength, as seen in the excerpt below:

During the discussions, there were a lot of people changed their minds, first because of how strong is the evidence and second the currency of the articles how they support the model (P5, Q4)

Analysis of responses of the post-test indicated that P5 was one of the four participants who had informed views of the validity of the information. To make informed decisions, P5 highlighted the importance of reading current articles that provide more updated information about the scientific issue. He also considered that it is essential to compare different viewpoints and experiences to search for and support the most convincing opinion, as illustrated in the excerpt below:

I like to see how updated this issue is to make a decision and to see how articles support each model, and to read more articles about what people and scientists think about their experience and my experience. I can compare them and see how scientific knowledge is structured and built compared to mine, and it really convinces me, and I will change (P5, post)

Participant 8. Analysis of responses in the pretest indicated that P8 had intermediary views regarding the validity of the information. She inferred that the availability of data regarding a specific claim ensures the validity of information and helps people make informed decisions, as shown in the excerpt below:

The available information is enough to make decisions (P8, pre)

After engaging in the first set of activities (Q1) in the context of climate change, P8 developed informed views. She recognized the importance of evidence in ensuring the validity of the information. Moreover, she highlighted the importance of validating the accuracy of evidence that support a particular claim, as seen in the excerpt below:

Evidence provided is not enough to make changes in the decision. Reasons to trust those evidence is also required (P8, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P8 also showed informed views of the validity of information and mentioned that evidence makes the conclusions valid. She explained that the validity of a specific claim increases as more research studies are performed, and more information is developed regarding the claim, as illustrated in the excerpt below:

What makes a data valid is when you recite data, and it is valid when it has facts and evidence in it to believe and trust the data. The data might be enough to prove that your opinions might be true but it better to find more data to really prove that you worked harder and proved that it is true (P8, Q2)

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P8 showed informed views and focused on the novelty of ideas and strength of evidence. She claimed that a piece of information is considered more valid when it is supported by new ideas and convincing evidence, as illustrated in the excerpt below

I think that model B is more supported [by evidence] than model A because all evidence are supporting model A because it's [Model B] an uncommon supportive idea that isn't really convincing (P8, Q3)

After engaging in the fourth set of activates (Q4) in the context of animal testing, P8 showed informed views and linked the validity of information to the availability of convincing evidence resulting from research studies. She also differentiated between valid information and opinion. She showed awareness that sometimes scientists give their opinions that might be incorrect, as seen in the excerpt below:

What makes a data valid is when they {scientists] find more convincing evidence and research, and they found what is the most convincing to them, but it doesn't really need to be right. It will be their opinion on it (P8, Q4)

Analysis of responses of the posttest indicated that P8 had intermediary views regarding the validity of the information. She only provided one idea and claimed that the validity of information increases as more knowledge is constructed about a particular claim, as illustrated in the excerpt below:

To make a better decision, it is important for people to know the negative effects of scientific products. Moreover, people have to know if the negative effects or diseases caused by scientific products are curable (P8, post)

Participant 22. Analysis of responses to the pretest that aimed to assess the participants' views of the validity of information indicated that P22 had intermediary views. Her views suggested that the validity of information is limited to the availability of data, as illustrated in the excerpt below:

More information is required regarding the effects of genetically modified food (P22, pre)

After engaging in the first set of activities (Q1) in the context of climate change, P22 already developed informed views regarding the validity of the information. She realized the importance of evidence for validating claims. Moreover, she highlighted the significance of having strong and current evidence to support a valid claim. She thought that a claim is considered more valid when stronger and more current evidence supports it, as shown in the excerpt below:

> *One of the human activities because the evidence strongly supports the model like the other one was not very strong. The evidence also is more current. Everybody knows that human activities are releasing lots of gases, so that's why [for solar system] there is no evidence ... there is no strong evidence there is no evidence that is exactly clear (P22, Q1)*

After engaging in the second set of activities (Q2) in the context of water fluoridation, P5 showed more than one informed view regarding the validity of the information. He thought that the strength of the evidence helps make a claim more valid, correct, and exact. P22 considered that as the number of strong, relevant and current evidence that supports the claim increases, the validity of the claim increases. She highlighted the importance of checking different points of view regarding an issue to evaluate different mindsets and choose the most valid, as illustrated in the excerpt below:

> *Model B because it has more evidence, and the evidence of it is more current. For example, the evidence that supports model A is since the 70s, and the evidence supporting model B is like 2009 like lately not old. It [validity] depends on the evidence… it depends on the information. We should know how this is correct. We should see what evidence supports it. The more things that are strongly supporting each evidence, the more accurate it is. I don't think I will change my point of view except they have more evidence for model A. I think*

model B is more valid because on the MEL diagram the evidence was more exact and it supported the model B strongly (P22, Q2)

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P22 claimed that the validity of information depends on the currency and the accuracy of evidence supporting it. Moreover, she considered that validity also depends on the number of strong, detailed, and exact evidence that supports the claim, as illustrated in the excerpt below:

I'm supporting what is more accurate and current. Model A because the research about it is more current. It says from 1950 to 1973 and 1989 they found evidence about model A, but the rest did not really show when they knew that and maybe the information is really old. And also, model A has more evidence. It has more things strongly supporting it. It's more accurate it's more exact the information it is detailed (P22, Q3)

After engaging in the fourth set of activities (Q4) in the context of animal testing, P22 showed informed views regarding the validity of the information that was similar to her previous responses. She claimed that the validity of information depends on the accuracy, currency, and precision of the evidence that supports the claims. She also considered that the validity of information depends on how people support the claim. She thought that supported positions have more possibility of being valid, as shown in the excerpt below:

The accuracy, currency, and how exact the info are the things that make data valid. Also, some models are more commonly supported, it has more evidence supporting it, and it is more accurate some people like most people support

Model B. It has more evidence supporting it, and it is more commonly supported (P22, Q4)

Finally, the analysis of responses of the post-test indicated that P22 had intermediary views regarding the validity of the information. Her views considered that validity of information is limited in knowing more about an issue as shown in the excerpt below:

To make a better decision, it is better to know more about the positive and negative effects of scientific products. I want to know if the genes they added or healthy (P22, post)

Differences in views of scientists. As shown in Table 6, analysis of the responses of the pre-test indicated that, out of sixteen participants, six participants (37.5 %) had naïve views regarding differences in the views of different scientists or individuals. Half of the participants (50 %) had intermediary views on the reasons for disagreements among the scientists (Table 6). On the other hand, only one participant (6.2%) had informed views of differences in the views of different scientists (Table 6). After engaging in four sets of activities (Q1, Q2, Q3, and Q4), analysis of the responses of the post-test indicated that none (0%) of the participants had naïve views about the differences in the views of scientists (Table 6). The participants having intermediary views dropped to two participants (12.5 %), and the number of participants has informed views about differences in views increased to 87.5% (Table 6). Below please find the detailed analysis of responses of three randomly selected participants to the question that aimed to assess their views on differences in science.

Participant 5. Analysis of responses of the pretest indicated that P5 had intermediary views regarding differences in views of scientists. He explained that every scientist has his or her opinions regarding a certain issue because they may have different viewpoints. He thought that these viewpoints might be right or wrong, as shown in the excerpt below:

It is not a problem is scientists disagree because everyone has a point of view, and there is a false or correct answer. There could be a lot of possible answers (P5, pre)

After engaging in the first set of activities (Q1) in the context of climate change, P5 developed informed views regarding differences in views. He was able to develop views about the reasons for having different views. He thought that scientists have different views because sometimes they want to hide their mistakes, as seen in the excerpt below:

Evidence data and research. Some people say model B is the reason because they don't want to show the world that it is our fault, but it is our fault (P5, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P5 gave more than one informed view regarding differences in views of scientists. He thought that scientists conduct research based on different points of view, study-specific problems differently, and end up with different results. P5 also mentioned that sometimes scientists might not publish their work when their data shows the negative consequences of their practices. Moreover, P5 showed awareness about the dependence of government's and people's decisions on scientist's opinions. He considered that people might be confused about which claim to support when scientists have different points of view regarding a certain problem, as shown in the excerpt below:

> *Some people study it differently than other people. Some people may discover something bad in fluorine, and the other group discovers something new, but they don't really want to publish the negative. It is a problem if scientists do not agree on one point of view because the government and business companies are affected by scientists' views. [It is a problem if the scientists do not agree] because every point of view in the government or the economy or business is all affecting one idea... It is affecting the others in a bad way or a positive way (P5, Q2)*

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P5 elaborated his informed views regarding differences in views. He thought that scientists have different views based on their different experiences and the information they gather through research studies. Moreover, he claimed that scientists might support different positions when the alternative positions endanger their financial benefits. He explained that scientists want their points of view to stand out to convince others with their opinions and maintain their economic and political influence, as illustrated in the excerpt below:

> *We have different data of that we came up with it, and besides the research, there are a lot of problems in the government that also makes it political which lead to a different point of views because they want their opinion to stand out and convince everyone because this will cause them an economic problem or financial problem. So based on what benefits they want and they don't want to*

show their mistakes, they don't want to lose anything financial or economic or political (P5, Q3)

After engaging in the fourth set of activities (Q4) in the context of animal testing, P5 showed more than one informed view and claimed that scientists have different views based on their differences in their values and principles. Moreover, He referred differences in views to differences in their ways of thinking and the level of their open-mindedness. Besides, he stated that the difference in views also depends on differences in scientists' background knowledge and experience, as illustrated in the excerpt below:

First articles and, of course, their scientific knowledge and how much did they have researched and how their mindset thinks and how ethical they think about animal testing. Different people do not have the same background, or if you want to say scientific knowledge, so they take as much as they have scientific knowledge; that is, they produce what they know. Second, experience their experience and the experiment so how much they do research and study about this thing. How the mindset thinks and how much you are open-minded (P5, Q4)

Analysis of responses of the posttest indicated that P5 had developed informed views of differences in views. P5 considered that it is common for scientists to disagree because different people develop different viewpoints when they have different prior knowledge and experiences. He thought that the difference in their prior experiences and knowledge has developed from conducting different research studies and reading different articles. These differences might lead scientists to come up with different conclusions regarding an issue, as shown in the excerpt below:

Based on the experience they have based on the research data/ info studies, based on articles. It is regular for scientists to disagree. Different people have different scientific knowledge which leads to different points of views. The scientific knowledge got from research and exact errors that they [scientists] have done can let you go open to lots of ideas, and you can't argue when coming up to a conclusion (P5, post)

Participant 8. Analysis of responses of the pretest that aimed to assess participants' understandings of differences in views showed that P8 had intermediary views before engaging in the different sets of activities. Her views suggested that differences in views are limited in differences in calculation methods, as shown in the excerpt below:

[They may have differences in views] because they might do another way of calculating (P8, pre)

After engaging in the first set of activities (Q1) in the context of climate change, P8 developed informed views. In addition to differences in calculation methods, P8 mentioned that scientists perform different experiments and analyze data differently. She also claimed that scientists of different views try to convince others with their point of view and agree on the most convincing view, as illustrated in the excerpt below:

All scientists have different opinions because they might do different ways of experimentation, calculations and analysis because they do different calculations and different ways and try easier and harder ways to see the final results or maybe they have something they didn't find out yet to know about it. In the end, they calculate, and they analyze it. They can find what the answer for *sure is in the end, they will try what they did, and they will see that it is more convincing than what they did before... (P8, pre)*

After engaging in the second set of activities (Q2) in the context of water fluoridation, P8 gave more than one informed view regarding differences in views. She thought that scientists support different views based on how much data and evidence they have, as shown in the excerpt below:

Maybe a group of scientists has less data or evidence to calculate and experiment, or They have done different researches from different websites, and they have tried it and didn't help them to solve their tooth cavity and had negative effects on their body, so that's why they have different opinions (P8, Q2)

P8 also showed awareness regarding the importance of agreement among scientists on a viewpoint because she thought that people act based on the claims provided by the scientists, as seen in the excerpt below:

People will start to believe one of the opinions, and maybe they do the bad thing. That is, the opinion that is bad, but scientists still did not discover that it is harmful and its negative effects that's why there should be one opinion so that all people follow that opinion (P8, Q2)

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P8 provided new ideas to explain her position regarding differences in views. She claimed that scientists support a certain point of view based on how they relate their prior knowledge and evidence with their current studies. P8 thought that people with a positive mindset want to stay optimistic. That is why they do not want to think about the negative consequences of scientific innovations. Besides, she mentioned that it is important for people to have the choice to support a claim, as seen in the excerpt below:

> *Evidence, data, and things that they have done before and that can be connected with the things they want to discover now. If you are a positive person and you want to stay positive, you always think that no it does not give you diseases to not worry about it so you can choose if you want model A or model B even you are forced to believe in one of them (P8, Q3)*

After engaging in the fourth set of activities (Q4) in the context of animal testing, P8 explained several reasons for developing different views. She thought that scientists support different views since they have different mindsets based on their experience and knowledge. She elaborated, suggesting that with time, scientists change their mindset as they gain more knowledge and experience. Moreover, she assumed that they start thinking more scientifically when they consider the opinions of other scientists and respect the ethical issues related to animal testing. She explained that some scientists might be against testing on certain animals considering other benefits that people receive from animals. She thought that these scientists might suggest testing on animals that do not benefit humans in other ways, as illustrated in the excerpt below:

> *All scientists, when they grow up, they will definitely have other opinions than others. They will think more scientifically or in another way. So, they might think of different opinions, but sometimes they may be wrong. And because of what they have seen and what they have been through animal testing like they have done animal testing. They have seen how it is working, and they are really*

disgusted. Some scientists who support model B and do not accept animal testing, they are thinking that animals are helping us to get dairy products and something like this from the farm. But in model A, scientists think that there are other animals that could help humans, but like mice and these types of animals, they don't do anything, so they are them. But in both ways, it is a bad thing for animals because animals and humans are basically the same (P8, Q4)

Analysis of the responses of the posttest showed that P8 scientists have different opinions because they follow different methodologies and observe their surroundings differently based on their prior knowledge, practices, and experience. She also mentioned that using different devices and sources of information leads to various views. P8 recognized the importance of agreement among scientists so that the people to make decisions based on agreed-on scientific knowledge, as shown in the excerpt below:

[They see things differently] maybe the types of the devices and the websites… what they have done before, what are their experiences that are done before so that everything that scientists do or practice on maybe they are different than the other scientists do so they have a different way of detecting things maybe it is correct, or maybe it is wrong, or it might lead to the same answer they might see that different objects of different items and they might be confused because of that? They use different steps and ways to see the cure or thing they need. Scientists need to focus on one opinion and one fact for all society to stay with them (P8, post)

Participant 22. Analysis of responses of the pretest that aimed to assess participants' understanding of differences in views showed that P22 had informed views of differences in views before engaging in any set of activities. She did not find a difference in views among scientists surprising. She explained that scientists disagree because they make different observations and develop different points of view. In addition, she thought that scientists make different judgments to differentiate true or incorrect claims.

> *I don't think it is a problem if scientists disagree, and I don't find surprising if scientists disagree because every scientist looks at the information from a different perspective, so they think of it in their own way. They might think that this person's opinion is wrong because they see it differently but the person they think of it differently (P22, pre)*

After engaging in the first set of activities (Q1) in the context of climate change, P22 also showed informed views of differences in views. However, she elaborated on the reasons for having different views. She explained that scientists disagree because they have a different point of view and understand data differently. She claimed that scientists choose to support a specific position based on their financial benefits, as illustrated in the excerpt below:

> *Also, some scientists might support the solar system ideas because they don't want to support the greenhouse gases since the gases come from factories and staff that make the gases. Some people work there so if they support that they might close the factories and that means they will not have any money, so maybe they are trying to support the other topic because they want money (P22, Q1)*

After engaging in the second set of activities (Q2) in the context of water fluoridation, P22 explained how scientists develop different opinions. She stated that scientists support different opinions because they observe and analyze data or evidence differently. Moreover, she claimed that ensuring financial and personal benefits might be a reason for supporting a particular view, as shown in the excerpt below:

> *Scientists may support different views as they get different information from different experiments. Based on their data and evidence, they support their idea. They also have different points of view, so they see stuff differently. Different scientists think about fluorine differently. For example, if a scientist is a dentist, they support model B because they don't want to lose their job and if people who are putting fluoride in the water and that is their job they are going to support model A because they don't want to lose their job either (P22, Q2)*

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P22 provided similar informed views regarding differences in beliefs. She stated that some scientists support a specific view to protect their jobs and keep on benefiting financially. Moreover, she claimed that scientists view the data from experiments differently, as illustrated in the following excerpt:

> *Maybe their point of view and the data that they get from their experiments. Maybe it is different, and most scientists want to protect their job. For example, people making technology, if they decided that model A is correct then the technology will be less, and they won't get as much money, but if model B is correct they will still have their jobs, but it is not helping people with their*

money and staff, so they are trying to support specific models because they don't want to lose their jobs and they want money (P22, Q3)

After engaging in the fourth set of activities (Q4) in the context of animal testing, P22 showed similar informed views of difference in views. However, she gave a new reason for developing different opinions. She restated that scientists have different views based on the different data collected from experiments, different ways of thinking, and various financial benefits. Moreover, P22 elaborated her response by mentioning that the difference in views also depends on personality traits. She considered that scientists support a particular position based on their feeling of empathy towards animals, as illustrated in the excerpt below:

The data of their experiments might be different, and the way they think and maybe they may support the model just because they want to see their jobs. For example, people whose job is to test on animals, they are going to lose their job if they decide if a model is an answer. So, they will lose their jobs and try to support model A so that they don't lose their jobs. The people who think it's ok to do animal testing like I don't think if they care about animals and they think that animals are not important. They are careless about animals, and they don't try to help the animals. It depends on their type of personality. People that are caring and nice support Model B as they care about animals because they love animals, and they think about how animals can help us in the future. But people who don't care about animals anything I think they will support model A because they don't care about the animals they don't care if the animals are suffering (P22, post)

Scientific Practices and Knowledge Construction. As shown in Table 7, analysis of the pre-test showed that none of the participants was classified as having informed views of scientific practices and knowledge construction. However, the analysis of the responses to the post-test showed a remarkable increase in the number of participants who have informed views on scientific practices and knowledge construction to 75%. On the other hand, in the pre-test, out of the sixteen participants, seven (43%) had naïve views of scientific practices and knowledge construction. Whereas, in the post-test, none of the participants showed naïve views of scientific practices and knowledge construction (Table 7). Furthermore, analysis of the pre-test responses showed that half of the participants (50%) had intermediary views (Table 7). After engaging in the different sets of activities, the number of participants having intermediary views decreased to three (18.7%) in the post-test. One participant did not answer the question on scientific practices and knowledge construction in both the pre-test and the post-test. Below please find the detailed analysis of responses of three randomly selected participants to the question that aimed to assess their views on scientific practices and knowledge construction.

Participant 5. Analysis of responses of the pre-test showed that P5 had intermediary views of scientific practices and knowledge construction. He thought that scientists construct scientific knowledge by analyzing laws and theories, as seen in the excerpt below:

> *Scientists produce scientific knowledge by thinking analyzing in every possible way to give facts laws and theories (P5, pre)*

After engaging in the first set of activities (Q1) in the context of climate change, P5 developed informed views on scientific practices and knowledge construction. P5 showed awareness that the construction of scientific knowledge might be a time-consuming process. He thought that scientists perform research, come up with theories, and discuss the validation of those theories. Moreover, he claimed that the validation of the theories requires further research that may take a longer time, as shown in the excerpt below:

> *I mean, when they [scientists] do research, they will probably still need time, but in the meantime, they come up with a theory or solution or what is happening and everything. But after a certain time, they will talk to each other to know, and they will know. If the theory is correct or it is false, they will share the results they got from their researches (P5, Q1)*

After engaging in the second set of activities (Q2) in the context of water fluoridation, P5 referred to new informed ideas to explain his views of scientific practices and knowledge construction. He thought that scientists construct scientific knowledge based on the data they collect through research on specific subjects. He elaborated his response by stating that scientists share their data with other scientists in articles and websites to convince. He added that scientists argue and respond to each other until they come up with a valid claim, as shown in the excerpt below:

> *Maybe they share ideas [to agree at the end] share their data and maybe find something that will help them to come up with a solution ... in articles ... websites. Scientists write articles to convince other people they do arguments*

responding to each other's information then they come up with solutions (P5, Q2)

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P5 showed informed views. He claimed that scientists construct knowledge by researching, experimenting, and coming up with conclusions. He thought that after making conclusions regarding an issue, scientists write articles about their conclusions and share their knowledge and experiences. He also stated that sometimes, scientists debate and argue to find a solution to their disagreements as illustrated in the excerpt below:

They are making conclusions about the experiments, research [and developing] scientific knowledge. They will write articles and debate then they will share these data and experience they will share their experience and background knowledge once they debate and argue and find the solution and then it will be solved (P5, Q3)

After engaging in the fourth set of activities (Q4) in the context of animal testing, P5 showed informed views about how scientists construct scientific knowledge. He explained that scientists construct knowledge by performing valid experiments and collecting data. He thought that scientists engage in discussions and might change their explanations depending on the strength and the currency of evidence that supports the claims as illustrated in the excerpt below:

Scientific knowledge is constructed based on the quality of the experiments. During the discussions, a lot of people change their minds based on first, of *course, how strong is the evidence and second the currency of the articles how they support and accept the model. (P5, Q4)*

Analysis of the post-test indicated that P5 had developed informed views of scientific practices and knowledge construction. He thought that scientists conduct their research studies and live their own experiences to construct scientific knowledge. Later, they share their experiences with other scientists through writing articles and arguing with each other, as shown in the excerpt below:

At first, they do their own research and studies, and they go to their experiences and share their experiences. Once they do that, they will write articles arguing or sharing their data for scientific knowledge. [They get the data] from the researchers they have done arguing with other scientists and from articles (P5, post)

Participant 8. Analysis of responses of the pre-test showed that P8 had naïve views regarding scientific practices and knowledge constructions. She stated that scientific practices and knowledge construction is limited scientific practices to performing experiments by using chemicals as shown in the excerpt below:

[They construct scientific knowledge] by trying experiments… maybe using chemicals (P8, pre)

After engaging in the first set of activities (Q1) in the context of climate change, P8 developed intermediary views of scientific practices and knowledge construction. She claimed that scientists do calculations and analysis of data to construct scientific knowledge depending on the data that convinces them most. Moreover, she developed an understanding of the cooperative nature of working in science. She claimed that scientists work together and check which claim is more convincing. They work together if they are not main rivals. She thought that they should have one opinion, as illustrated in the excerpt below:

> *At the end they calculate and analyze data so they can find what is for sure at the end, they will try what they did, and will see that it is more convincing than what they did before... they will work together and will have one opinion and that is better, will help each other if they are not hal2adde really against each other (P8, Q1)*

After engaging in the second set of activities (Q2) in the context of water fluoridation, P8 was able to develop informed views of scientific practices and knowledge construction. She claimed that scientists construct knowledge as they experiment and find a new way of performing calculations to come up with an opinion or a fact. She explained that scientists continue performing experiments to analyze and recheck the validity of their opinions. In this process, they may find out new information. Scientists check on what other scientists are doing as well. Then, scientists talk to each other to agree on one answer or fact. She thought that they might debate or start working with each other, as seen in the excerpt below:

> *[To agree] they will check and recheck what they did, and they will try to see they analyze the ways they came up with the idea that fluorine prevents tooth cavity... Maybe it is not a tooth. Maybe they discover new things. Maybe start debating and maybe start to work together to maybe. Maybe both of their opinions will make another opinion and another fact. They need to talk together to end up with one answer, a fact. They see what the two groups of scientists do,*

and they try to figure out a way, another way to calculate to experience and to find the opinion or the fact (P8, Q2)

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P8 showed informed views and claimed that scientists collect data from all around the world and analyze it. She explained that scientists report their data and share their evidence with other scientists. They might falsify information that was discovered earlier. Scientists work together to tell each other what they have done and what data they have collected. She elaborated telling that scientists discuss the available proof, a debate in case they find mistakes in the previously performed procedures, correct and combine evidence, and come up with a new conclusion as illustrated in the excerpt below:

If anyone around the world happened to him something, they could report the scientists or any person to analyze. First, they will see the mistakes they have done before so that they correct things so that they combine all the evidence and the proof they have like the both scientist and come up with a new thing different than Model A and B they might find a model C. they can work together they can debate tell each other while debating they can tell each other what they have done and the proofs they have so both of them really discuss about it and see what would work (P8 Q3)

After engaging in the fourth set of activities in the context of animal testing, P8 did not elaborate on her answer and showed intermediary views of scientific practices and knowledge construction. She claimed that scientists work together and do not let their disagreements lead not to find solutions. She thought that scientists debate for the sake of finding solutions or alternatives for animal testing, as seen in the excerpt below:

> *They will debate and see different solutions as they forget about their opinions, and all scientists like nothing has happened they try to see what could they do like another solution of animal testing so that they can find another solution not to harm animals or humans (P8, Q4)*

Analysis of the post-test indicated that P8 showed more than one informed views on scientific practices and knowledge construction again. She considered that scientists find a problem to solve. She explained that scientists start to construct scientific knowledge by making observations, performing experiments, and finding data or evidence. They compare their discoveries with the data that was previously constructed and identify their similarities. They might connect evidence to the predictions made by scientists. They also read other research studies to know about the existing knowledge about the problem. If necessary, they create new devices and technology to make better experimentations. She added that they publish their results, discuss them with other scientists to study their points of view, and make decisions regarding the correct findings. They make predictions based on the evidence provided and find relationships between variables. She also stated that scientists also discuss their results with the people of the society and the government, as illustrated in the excerpt below:

> *First, they try to think of a case so that they find something to find the cure of the situation. What they need to prove is correct or what they need to find the cure of this thing. So they try to see what it looks inside and outside or to see the*

similarities that they have seen before. Let's say, for example, similarities between animals and humans. So if they see that they have similarities, for example, they do animal digestion in humans. Then, they see researchers' news and other things they knew before. They try to create a new technology or a new device so that they can detect the thing that they are searching for. They will publish it, and they will talk to the society and the government and all this type of things. They will talk to other scientists with other cases so that they see what their opinion is so that they see if they are correct or wrong so that it will be balanced. From the evidence that they found the data or what people might predict, they connect the things that people predicted so that they come up with one answer (P8, post)

Participant 22. Analysis of the responses of the pre-test indicated that P22 had intermediary views on scientific practices and knowledge construction. She thought that scientists perform experiments and do calculations to produce scientific knowledge, as seen in the excerpt below:

They use experiments, and they try doing stuff, they try stuff, for example, what is the boiling point of water. They will do experiments (P22, pre)

After engaging in the first set of activities (Q1) in the context of climate change, P22 also showed intermediary views of scientific practices and knowledge construction. However, she recognized the importance of cooperation and agreement among scientists in the process of constructing knowledge. She claimed that scientists construct knowledge when they find and agree on the absolute answer. To agree, they need to listen to the other point of views and try to understand, as shown in the excerpt below:

To know the answer, the actual answer about climate change, they need to listen to the other point of view and see what is difficult to understand and maybe they will know the answer (P22, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P22 was able to combine her previous intermediary views to show informed views of scientific practices and knowledge construction. She explained that scientists construct knowledge by collecting data and evidence, writing about their views and understandings, as well as looking at other different points of view. Then, they figure out ways to prove that their views are correct, meet with other scientists, talk to them, and listen to their point of view or read their articles from websites. She claimed that the two groups of scientists might debate and try to disprove the information of the opponents' websites by posting information on their website, as shown in the following excerpt:

They looked at different points of view, and they got more data and evidence, and in the end, they wrote. Like when they saw the other point of view, they understood what other people see, and they knew how to show how their idea is more correct. They should meet and talk to each other and listen to the other points of view on websites. They state their ideas on the other website. The other group of scientists proves that that website is wrong by putting it on their website and they debate over it on the websites (P22, Q2)

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P22 had informed views on scientific practices and knowledge construction. She thought that scientists perform research studies and experiments to collect data and evidence. She thought that as scientists do many experiments, they compare the results of the experiments and share them with other scientists. She explained that scientists talk to other scientists and find commonalities in evidence. They check for the stronger evidence available to understand better the results as illustrated in the excerpt below:

> *They do experiments and researches. They get data and get the evidence. They do many experiments and compare the results. They should listen to each other's opinions, they should talk, and they should check what the common things in the evidence and they see each other's evidence to see which is stronger and put them together and understand the result (P22, Q3)*

After engaging in the fourth set of activities (Q4) in the context of animal testing, P22 showed similar informed views, as shown in the previous questionnaires. She thought that scientists construct scientific knowledge by sharing their data/evidence, meeting with other scientists and listening to their viewpoints, comparing their data and finding commonalities, making a decision or agreeing on the most convincing data as shown in the excerpt below:

> *[Scientists construct knowledge] by listening to other people's points of use. If scientists want to decide on one model, they should meet. Maybe not meet, but they should talk to each other and listen to each other. They have to see the common evidence and common data, and they come up with a decision (P22, Q4)*

Analysis of the post-test indicated that P22 had developed informed views of scientific practices and knowledge construction. She claimed that scientists construct scientific knowledge by researching, finding data and evidence through experimentation, negotiating with other scientists, listening to their points of views and compare ideas, finding commonalities between results, writing books and articles for websites and spreading their knowledge so that everyone can learn about it as illustrated in the excerpt below:

> *When they research, get evidence and data, they negotiate and listen to different points of view. They do many experiments and do a lot of research, and after that, they are far with their research then they communicate with the other scientists, and they see the different things that they came up with and the common information just do more experiments, and in the end, they will go into have an idea a specific idea out of the common ideas that the other scientists have come up with. They communicate in website and books so that it can get around the world so that people can study it (P22, post)*

Relationship between science and society. Table 8 shows the results of the analysis of the responses of the participants to the pre-test and post-test regarding the relationship between science and society. This analysis showed that none of the participants had informed views of the relationship between science and society in the pre-test. However, analysis of the open-ended questions in the post-test showed that nearly half of the participants (56.2%) developed informed views. On the other hand, out of the sixteen participants, five participants (31.2 %) were classified as having naïve views in the pretest (Table 8). The number of participants having naïve views dropped in the post-test, and none of the participants had naïve views of this theme. Moreover, analysis of the responses of the pre-test also showed that 50% of the participants had intermediary views about the relationship between science and society, while in the post-test, only six participants (37.5 %) had intermediary views (Table 8). Below please find the detailed analysis of responses of three randomly selected participants to the question that aimed to assess their views of the relationship between science and society.

Participant 5. Analysis of the pre-test indicated that P5 has intermediary views about the relationship between science and society. His views showed that the relationship between science and society is limited to talking about scientific topics in society, as shown in the excerpt below:

The society may talk about scientific topics (P5, pre)

However, after engaging in the first set of activities (Q1), P5 already developed an informed view and stated that science is related to society in certain environmental issues. He explained that society contributes to increasing the level of pollution with a careless attitude regarding burning fossil fuels and trash. So, climate change is caused by the activities of the society. He thought that climate change and polluting gases are affecting society as more types of diseases, viruses, and bacteria are diagnosed compared to the past. Also, P5 mentioned that climate change is causing the extinction of animals, as they are not able to find food anymore, as shown in the excerpt below:

We as people are ruining our dear planet because viruses are being seen around us as a result of climate change and from the gases. We are increasing the bacteria and viruses, and we are not able to have a cure for it. Animals are getting extinct, decreasing the nutrition and the amount of food they have (P5, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P5 showed informed views of the relationship between science and society. He explained that fluoridated water, which is a scientific product, is consumed by society. He thought that, in a way, science is forcing people of society to intake mediation and causing diseases. He also claimed that people in the society take decisions regarding consumption of certain products based on the evidence provided and articles published by the scientists as shown in the excerpt below:

> *People would take fluoridation by being forced to without knowing. It is related to society because it is related to people's health, and society is being forced to take medications that may harm their bodies without knowing. So it is all related to us people are making decisions to drink or not based on the articles and the evidence published by the scientists (P5, Q2)*

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P5 also showed informed views on the relationship between science and society. He thought that science might create chaos in society if the cause of the problem by the scientific products are not solved. Moreover, he mentioned that people in society have different opinions regarding the production of technology. Some people consider that modern society is highly dependent on technological devices, which are scientific products, and people cannot stop using technological devices. This may create misunderstandings and arguments among them. He suggested scientist consider people's opinions when producing technological devices, as shown in the excerpt below:

Maybe we don't come up with a solution to solve both Models [of electromagnetic wave pollution] it will be a chaos. We should take the opinion of people. Comparing the past and present, technology has changed and improved, and it is constantly improving. So, more electromagnetic wave developed because it turned out to be we need the radiation for it [technology] to work (P5, Q3)

After engaging in the fourth set of activities (Q4) in the context of animal testing, P5 also gave informed views of the relationship between science and society. He claimed that society is related to animal testing because society benefits from animal testing and gets accurately tested medications without harming humans. Science helps people to receive medications and be protected from diseases. On the other hand, he mentioned that people harm the animals by performing scientific experimentations and cause changes in the food chain, as shown in the excerpt below:

[The society is getting] doubtful medication we are not sure if the medication will work on us, so we tested on the animals. If we or society gets the wrong medication, it can lead to virus sickness and a lot of harmful diseases, which can cause great damage to humanity. We will be using our food diet since we are harming the animals which can also lead to extinction (P5, Q4)

Analysis of responses of the post-test indicated that P5 had developed informed views on the relationship between science and society. First, he stated that science is related to society because people have their opinions and make decisions regarding scientific issues. Moreover, he claimed that science helps improve people's health and prevent them from diseases by providing the appropriate medication and solving health problems. Besides, he thought that people in the society are subjected to the risks of wrong medications that produced through scientific studies, as shown in the excerpt below:

> *Yes, because people have their opinions too. The easiest example that I can get is that it is water fluoridation because it is all about the society and the health of society. Science is everywhere, and society is part of science because if society takes the wrong medication, it can lead to problems that are from the cause of science. Maybe people are getting a wrong medication which is causing problems and their heath (P5, post)*

Participant 8. Analysis of the pre-test indicated that P8 had intermediary views when explaining the relationship between science and society. She thought that the relationship between science and society is limited to finding cures for people's diseases, as shown in the excerpt below:

> *Science is related to society because science is related to the health of people. Science helps in finding medication and cure for diseases (P8, pre)*

Engaging in the first set of activities (Q1), in the context of climate change, was enough for P8 to develop informed views on the relationship between science and society. Besides reclaiming that society is related health of people, she mentioned the role of science in protecting nature and the planet. She elaborated her response, mentioning that science is related to society because society also contributes to problems such as climate change. Society is causing pollution. Scientists say that climate change is because of pollution. Consequently, she thought society is related to science, as illustrated in the excerpt below:

Science is all about health, government and society. They are related to each other because of curing people and harming the planet. When men are polluting that is related to science and society. They [scientists] are telling us to stop pollution and causing climate change so that's why they are related. So everything related to society is related so science (P8, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P8 showed more than one informed view regarding the relationship between science and society. First, she claimed that science is related to society because medical and scientific research is related to the health of the people. Science helps and influences people's wellbeing. Second, she showed awareness that society decides if they want fluoridated water to be sold in their society and for what price. Therefore, people have to make some decisions regarding scientific issues like water fluoridation. She stated that people follow scientists, as well as make decisions based on what scientists believe, referring to the claims given by scientists. Third, she mentioned the risks of scientific products such as fluorinated water on the health of the people and highlighted the importance of science in guiding people for proper usage of medications. She explained that if fluoridated water is available publically, there would be no control over the amount of the fluoride intake. Thus, people may intake fluorine in greater amounts and are harmed. Finally, P8 mentioned that scientific innovation affects the majors that people study at the university. She assumed that when dentists start to profitless because of the benefits of water fluoridation, fewer people might be motivated to study dentistry in the university, as illustrated in the excerpt below:

Science is medicine and things related to health; they found out new things about nature that can help us and help anyone. People will start to believe one *of the opinions, and maybe they do the bad thing that is the thing the bad opinion because scientists still did not discover that it is harmful and it has negative effects. That's why, there should be one opinion so that all people follow that opinion. The society is basically the one to decide if they want water fluoridation or not. They decide if they want to sell it or not, where do they want to sell it how do they sell it, the prices like the financial things. They [people] will not study things related to dentists in the university (P8, Q2)*

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P8 elaborated her responses with new informed views to describe the relationship between science and society. She stated that science has positive and negative effects on people. Science improves the quality of life by creating machines. People in society use products created by science such as phones and computers for positive purposes and on which they become highly dependent. However, they are affected negatively, like developing cancer or visual problems. She thought that people in society have to agree if they want to use technology or not without being forced to. To show their agreement regarding an issue, people engage in democratic practices such as voting. She claimed that people in society follow the opinions of scientists to make decisions. She considered that if scientists disagree, people get confused and start to argue. Furthermore, she mentioned that science is related to society because scientists have to follow social laws when creating new technology, as shown in the following excerpt:

In general, society is equal to science because scientists should follow the law to create things, and what I mean by things is technology. Scientists created the machines and X-ray improved the quality of life. Science finds medicine and *cure for diseases; on the other hand, it causes diseases. So, if technology is related to science, science is related to society. If the scientists discovered a new device like a phone or anything like that, the society would decide if they want to sell it to the people so they try to vote it is a problem if the scientists do not argue because it will make a huge difference in between people anyone could argue that is you don't really know the right or the correct answer about it, and it will make the world confused, so it is better to have one opinion (P8, Q3)*

After engaging in the fourth set of activities (Q4) in the context of animal testing, similar to the responses of the previous questionnaires, P8 showed informed views on the relationship between science and society. She claimed that people had developed different opinions regarding animal testing. People of society decide to support or oppose animal testing based on the negative influences of animal testing. She thought that society might permit scientists to act in a certain way or oppose their behavior. The society supports scientists to perform animal testing when it does not oppose or complain about it. Moreover, she stated that science provides medication for the people of society and puts them at the risk of receiving the wrong medication as well. She explained that scientists try medication on animals, but sometimes they get different results when applied the same medication on humans. Therefore, science may harm humans because of its experimental errors, as illustrated in the excerpt below:

Society decides if they want to do animal testing or not. Scientists might have made a mistake, and maybe they have realized something as of animal testing, a not after a day let's say. So, they don't know if animal testing is a good thing because they think that they [animals and humans] have different cells, different things [ways of] how they digest and how they grow. Society is trying to help the *scientists to do animal testing because they are confirming they are giving the animals. It is not like they are supporting them, but they are not standing against their opinions. So they are helping them how to do animal testing. Science may help society by the animals' medicine because of animal testing. They have found a vaccine. It isn't working for humans that could be a thing where they can use animal testing so the society will definitely keep on supporting scientists to do more (P8, Q4)*

Analysis of responses of the post-test revealed that P8 had developed informed views on the relationship between science and society. She stated that science is related to society because it improves the ways people live. Science finds medication for people and solves health problems. On the other hand, she thought that people might be forced to use scientific products and develop diseases. Therefore, this reason, she considered that people of society have different opinions regarding scientific issues. They may agree or disagree. She stated that society *decides* how and at what price the scientific products are sold, as shown in the excerpt below:

Because science makes our world better. Science is related to society since, for example, the genetically modified food the society despises if they want to sell it how they want to sell it and where do they want to sell it. Or, for example, the water fluoridation. Society decides how they want to sell it the price for sure. They want to ask how it works because they can't sell something, and they don't know what it is or have it work. Society will agree or disagree with scientists, and scientists discovered things that are now laws. Maybe scientists are forcing them to sell genetically modified food you won't really feel like the society would agree that if it is a good thing or not they don't know because they have different *opinions. So we may think that they might be convinced that it should be sold (P8, post)*

Participants 22. Analysis of responses of the pretest indicated that P22 had intermediary views on the relationship between science and society before engaging in the activities. She related science to society because she considered that science is associated with everything that is around people, as shown in the excerpt below:

Science is related to society because science is all around us (P22, pre)

After engaging in the first set of activities (Q1) in the context of climate change, P22 already developed informed views on the relationship between science and society. She claimed that science is related to society because scientific discoveries allow people to know more about their lives and surroundings. She considered that science tackles some problems faced by people and aims to suggest solutions to those problems. Moreover, she thought that science is related to society because people argue about different scientific issues. Besides, she stated that people contribute to creating environmental problems like climate change. She thought that these environmental problems are affecting the nature and people's lives negatively by causing diseases, drought, extinction of plants and animals, reduction of food supply to humans as illustrated in the excerpt below:

Science is related to society first because first people might not agree on certain issues, but it [science] makes us know more about our lives, and people become more aware of stuff happening everyday... like climate change is a problem our air… and science is showing it to us so that we do something about it. Some plants are dying and maybe in some places, water is drying up, and animals are *not able to live, and humans need to eat plants and animals to live. The farmers and planters are not going to have money if they can't plant anymore. They will not have food, and they will not have money, and they will not survive (P22, Q1)*

After engaging in the second set of activities (Q2) in the context of water fluoridation, P22 also showed informed views. She thought that science makes people aware of certain hazards and gives recommendations to act in a certain way. Moreover, she thought that scientific innovations are applied to and used by the people in society. Furthermore, she mentioned that sometimes, people are forced to apply scientific products in their lives, as shown in the excerpt below:

Also, it tells us what the staff is bad for us. What we should do. It is forcing society to drink something they don't want to. Maybe they already go to the dentist once a week to take fluoride. They are also forced to drink it in the water (P22, Q2)

After engaging in the third set of activities (Q3) in the context of animal testing, P22 showed similar informed views as the responses of the previous questionnaires. She claimed that some people in society contribute to making technology created by science, while others buy them. She considered that people of society expose themselves to electromagnetic waves by using electronic devices and emitting electromagnetic waves. People debate about scientific issues. Moreover, she thought that people's decisions regarding scientific issues depend on the agreements of scientists. She explained that people rely on the scientific knowledge constructed by the scientists and include this knowledge in educational books to pass it to the other generations.

The people in the society are making new technologies, others buy it, and when they use it, it makes waves. If society were not buying the technology, we would not have this problem. The society is buying technology, and it's making the electromagnetic waves; this is why people are debating about it. Everyone has different points of view, but it might affect society. It will be what people follow, and it will be scientific information, scientific knowledge then maybe they will write it in books for children to study at school (P22, Q3)

After engaging in the fourth set of activities (Q4) in the context of animal testing, P22 showed informed views to explain the relationship between science and society. She thought that scientists are performing tests on animals to supply medications that will protect people from diseases. She elaborated, telling that scientists prefer harming animals instead of harming the people of society. However, she mentioned that sometimes scientists put people at the risk of getting the wrong medication because she thought that occasionally animal testing experimentations do not provide accurate results as shown in the excerpt below:

Scientists are testing on animals in order not to harm the society. They do animal testing to test the medicines and drugs on the animals before they use it on humans because they think that the animals do not matter as much as humans. So losing an animal is not as important as losing a human. So that's why they do it on animals. The people are the ones that are testing the animal. The scientists are testing on the animals for the people. (P22, Q4)

Analysis of responses of the post-test indicated that P22 had developed informed views on the relationship between science and society. She thought that science is related to society because society makes and uses scientific products in their everyday life. People use science and technology to improve their standards of living.

On the other hand, she mentioned that people benefit from scientific products such as medications. However, scientific products might affect people negatively, as well. Additionally, she said that society contributes negatively to scientific and environmental issues. In return, she thought their survival on planet Earth is becoming challenging, as shown in the excerpt below:

> *Yes, I think it is related because society is making technology and science they are following the science to get more advantages in life like in technology they are following signs to make it more stuff like that… it is happening in our daily lives because, for example, in animal testing or electromagnetic waves. Like animal testing, society is fighting to find the answers because if animal testing kept going, it might affect society in a bad way. Also, the electromagnetic waves are related to society because society is exposed to electromagnetic waves. Moreover, climate change is affecting society because actually, the society is affecting the climate change because they are the ones who are polluting, but it is going to affect them later because the temperature in the country will make the water dry in the country and they will die, so it is affecting them also (P22, post)*

Relationship of science and politics. Analysis of the responses of the pre-test presented in Table 9 showed that six participants (35.7 %) had naïve views regarding the relationship between science and politics. Analysis of the answers to the questions of the post-test indicated the number of participants who had naïve views of the relationship of science and politics decreased sharply to zero (0%) as none of the participants showed naïve views. On the other hand, eight participants did not answer the question on the relationship between science and politics in the pre-test. However, after engaging in four sets of activities, four participants did not respond to this question. Additionally, analysis of the pre-test showed that none of the participants had informed views on the relationship between science and politics. Whereas, in the post-test, the number of participants showing informed views remarkable increased. Half of the participants (50%) showed informed views in the post-test. Moreover, in the pre-test, only two participants (12.5 %) had intermediary views (Table 9). Analysis of the answers to the questions of the post-test indicated four participants (25 %) showed intermediary views when relating politics to science (Table 9). Below please find the detailed analysis of responses of three randomly selected participants to the question that aimed to assess their views of the relationship between science and politics.

Participant 5. Analysis of the responses of the pre-test indicated that P5 is one of the two participants who showed intermediary views on the relationship between science and politics. He claimed that science is related to politics in certain topics only as shown in the excerpt below:

> *[Science and politics are related] depending on the topic (P5, pre)*

After engaging in the first set of activities (Q1) in the context of climate change, P5 stated that people protest when they do not agree with policies regarding science, as shown in the excerpt below:

> *When something is going wrong with science and politics the people protest and make fire (P5, Q1)*

After engaging in the second set of activities (Q2) in the context of water fluoridation, P5 showed awareness about how governments take decisions regarding fluoridating water in the country based on the scientific knowledge on which scientists agree as shown in the excerpt below:

> *[It is a problem if the scientists do not agree] because every point of view in the government or the economy or business is all affected by one idea. It is affecting the others in a bad way or a positive way and on the decisions the government takes. Political wise [politically] depending on the decision they make it may lead to the society be forced to drink fluorine or not (P5, Q2)*

Engaging in the third set of activities (Q3) in the context of electromagnetic waves, pollution helped P5 to developed informed views on the relationship between science and politics. He was aware that the government or politicians make decisions regarding problems that are created by science. However, he thought that sometimes politicians support a certain claim to protect their financial benefits. She explained that they convince others to support their positions so that they keep on profiting from the production of technology, as shown in the excerpt below:

> *The governments take the decision about this issue; maybe this is the political part. besides the research, there are a lot of problems in the government that also makes it political which lead to different point of views because they want their opinion to stand out and convince everyone because this will cause them economical problem or financial problem so based on them and what they want benefits and they don't want to show their mistakes they don't want to lose anything financial or economic or political (P5, Q3)*

In the context of animal testing, after engaging in the fourth set of activities, P5 showed intermediate views on the relationship between science and politics. He only mentioned the role of the government in making decisions regarding scientific issues. He claimed that the government decides to perform animal testing or to replace it with technology, as shown in the excerpt below:

[The role of the government is] to make the right decision and to build on evidence 6 which is developing and improving technology to replace animal testing (P5, Q4)

Analysis of the responses of the post-test indicated that P5 had developed informed views on the relationship between science and politics. He considered that science is related to politics because politicians of the government make decisions regarding certain environmental problems caused by scientific issues. He also mentioned that politicians require people to act in a certain way, depending on scientific notions. For example, he thought that governments demand from factories to reduce the production of toxic gases, as shown in the excerpt below:

[The role of the government] is the main part is to convince and to make the right decision. For example, about the climate change for the factories and providing Solutions while convincing them that it is wrong to produce smartwatches from the factory (P5, post)

Participant 8. Before engaging in the four sets of activities (Q1, Q2, Q3, and Q4), P8 showed naïve views on the relationship between science and politics in her responses of the pre-test. She thought that science is not related to politics because politics is related to history, while science is not as shown in the excerpt below:

Science is not related to politics because the latter is related to history. History and science to do not work together (P8, pre)

After engaging in the first set of activities (Q1) in the context of climate change, P8 developed intermediary views on the relationship between science and politics. However, she only claimed that science is related to the government, as shown in the excerpt below:

Society and science are related to the government (P8, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P8 also showed informed views that relate science and politics. She related science and politics by relating science to governments. However, she elaborated her answer mentioning the role of governments in making decisions regarding the production of scientific products, as well as the employment and financial problems of people who work in scientific fields as shown in the excerpt below:

The governments take the decision of how scientific products should be sold to control the economy and the unemployment rate in the country. So what the government may do is that they don't sell it in the supermarkets and the dentist cancel it so they will take the money and everyone will be working (P8, Q2)

In the contexts of electromagnetic wave pollution and animal testing, after engaging in the third and the fourth sets of activities Q3 and Q4 respectively, P8 did not respond to the question and did not relate science to politics.

However, the analysis of the responses of the post-test indicated that P8 had developed informed views on the relationship between science and politics. She explained the role of the government in testing and ensuring the safety of scientific products before making them available to the public. She also explained how the government is involved in making decisions regarding the ways of selling scientific products, as shown in the excerpt below:

> *When you are studying something like medicine, it is from the scientists creating this medicine to cure this type of sickness and government's they may be testing it or checking it before they are selling in the supermarkets to people or storing by the doctors in workplaces and pharmacies (P8, post)*

Participant 22. In the pre-test, analysis of responses to the question that was aiming to assess participants' views on the relationship between science and politics indicated that P22 did not answer the question. However, after engaging in the first set of activities (Q1) in the context of climate change, P22 already had developed informed views to relate science and politics. She showed awareness of how politicians might argue about different points of view regarding a scientific issue like climate change. Moreover, she mentioned that politicians might ignore the adverse effects of scientific products on the environments and decide to support a specific argument that guarantees their financial benefits, as shown in the excerpt below:

> *Maybe the politicians will fight about closing the factories or not because they want money in the country, but some politicians care more about the earth so they fight about that (P22, Q1)*

After engaging in the second set of activities (Q2) in the context of water fluoridation, P22 also showed informed views. She claimed that politicians make decisions and debate over the application of scientific innovations in society. Moreover, she assumed that disagreements among politicians regarding scientific issues might lead to termination of the production of certain scientific products. Financial problems related to the production of scientific products may lead to organizing protests in society. In these conditions, P22 thought that the government asked for donations from organizations or other countries to higher the reputation of the country, as shown in the excerpt below:

> *Different politicians might fight about different points of view. Politicians might debate, and there might be protests. It affects the economy since if they support model A [fluorine prevents tooth decay]. Dentists will lose their jobs. Either way, the country will become weaker. The politicians maybe talk to other organizations, and so they have more money in the country. They support a certain model to have more money in the country for the reputation of the country will go down (P22, Q2)*

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P22 showed more than one informed view to describe the relationship between science and politics. She stated that even if people support a specific position regarding Electromagnetic Wave emission, in the end, the government takes the decisions regarding this issue based on scientific knowledge. She also claimed that some politicians prioritize their financial benefits and support the position that keeps them profiting. The decisions taken by the government may not always be beneficial to the people. Moreover, she thought that people argue and complain about the decisions made by the government regarding scientific issues because these decisions may influence the economy of the country, as shown in the excerpt below:

When scientists have different viewpoints regarding an issue, politicians get confused and debate about the decisions that they may take. It will be easier for the government to make decisions if scientists agree. If they want to stop technology but they don't know the answer, yet they will be confused if they stop the technology or not. They will be fighting about what decision they should make. But if they have the answer, it will be easier. Moreover, maybe in some countries, politicians might fight about the different models, and they won't know how to make a decision for society. Because if they made a decision in the end about model A or model B, it affects the decision of making less technology or even stopping it, or they keep it going on if model B is the answer. If they produce more, the people will buy then, and the people will pay so they would have more money, but if they stop, the economy will be low in the country, and they won't have money a lot. They are protecting their jobs. Some people support Model B. They try to protective jobs so that they don't lose their money. Some people like to say this about model B because they don't want to stop producing devices so that they protect their jobs (P22, Q3)

In the context of animal testing, after engaging in the fourth set of activities (Q4), P22 did not respond to the question about the relationship between science and politics. However, analysis of the responses of the post-test showed that P22 showed informed views to related science and politics. She thought that politicians in the government follow scientific knowledge to make certain decisions and make changes in society. She also stated that politicians might argue and disagree about the different opinions of the scientists, as shown in the excerpt below:

The governments work with scientists and organizations to answer to society. sometimes, for example, the government wants to shut down the factories because it is creating pollution, so they need to shut it down. the government is following the science to make different answers and to make different decisions (P22, post)

Relationship between Science and Economics. As shown in Table 10, analysis of the responses of the pre-test indicated that, out of sixteen participants, nine did not respond to the question. Whereas, in the post-test, only two participants (12.5%) did not respond to the question. Moreover, in the pre-test, five participants showed a naïve view by mentioning that science and economics are not related to each other. However, the number of participants having naïve views decreased in the post-test. None of the participants showed naïve views in the post-test.

On the other hand, only one participant had intermediary views on the relationship of science and economics on the pre-test, whereas 25% of the participants had intermediary views on this theme at the end of the study (Table 10). Finally, the analysis of the pre-test indicated that none of the participants had informed views on this theme. The number of participants who have informed views of the relationship between science and economics increased to 62.5% in the post-test (Table 10). Below please find the detailed analysis of responses of three randomly selected participants to the question that aimed to assess their views of the relationship between science and economics.

Participant 5. In the pre-test, analysis of responses to the question that aimed to assess participants' views on the relationship between science and economics showed that P5 was the only participant who had intermediary views. He considered that science and economics are related only in particular topics, as shown in the excerpt below:

> *Science is related to economics depending on the topic (P5, pre)*

After engaging in the first set of activities (Q1) in the context of climate change, P5 already developed informed views on the relationship between science and economics. He explained that people in charge of factories deny the fact that human activities cause climate change to ensure the sustainability of their business and continue profiting. Moreover, he claimed that Climate Change might have a negative influence on particular professions and exemplified the case of farmers, as shown in the excerpt below:

> *Let's say the factories. They obviously are polluting etc. They don't want to say it is from the factories so that they don't lose business, so that they say it is from the solar system. The farmers will lose their work, and they will become baggers (P5, Q1)*

After engaging in the second set of activities (Q2) in the context of water fluoridation, P5 showed similar informed views. He explained how scientific innovations might influence people's professions negatively and result in serious financial problems. In this context, he exemplified how dentists might face financial difficulties when people benefit from fluoridated water, and fewer patients visit them, as shown in the excerpt below:

> *Dentists will lose money because they will not have patients to cure them of tooth cavity (P5, Q2)*

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P5 elaborated his previous informed views. He claimed that specific factories that produce electronic devices might close as the production of these devices decreases because of their negative influence on people's health. This causes financial problems for the people who work in the factory. Moreover, he gave another relation between science and economics by stating that people in society might have medical expenses as they pay money to be cured of the diseases caused by technology. He explained that sick people in society would not be able to go to work. Therefore, people will profit less or not have income at all, as shown in the excerpt below:

Since it causes cancer, everyone will be in the hospital because we need a cure, and no one will have a job because factories will close, and others will all be sick, and now if it is true that model A is causing cancer the technology products will be selling less. There will be no money (P5, Q3)

After engaging in the fourth set of activities (Q4) in the context of animal testing, P5 showed similar informed views as in the previous questionnaire. He claimed that science is related to economics because as certain scientific practices such as animal testing become forbidden, people may lose their jobs and face financial problems. Moreover, people might develop diseases and spend money to be cured, as shown in the excerpt below:

People doing animal testing will not work and not have money because they don't want to do it depending on the political decisions. If they support model A it can cause damage for the animals and the human because if humanity gets the *wrong medication if animal testing stops and get diseases and buy medications (P5, Q4)*

Analysis of the responses of the post-test showed that P5 had developed informed views on the relationship between science and economics. He explained that products that are created by science are sold to people. Some of these products, like medications, may be expensive. This might cause people to face financial problems when they need to buy them. He gave another example of economic problems caused by science as well. He thought that manufacturing scientific products might require the production of greenhouse gases, causing depletion of the ozone layer and other environmental issues. As the factories are forced to reduce the production of these gases, people working in the factories profitless or become unemployed.

Economically, the things that people produce is from science. Water fluoridation, for example, if we sell fluoridated water it may be expensive because it is a cure. Factories, for example, when they produce carbon dioxide or the smoke to the atmosphere it is causing a depletion in the ozone layer which is causing the Earth to have atmospheric problems and when the factories are forced to shut down which leads to decrease in money (P5, post)

Participant 8. Analysis of responses of the pre-test indicated that P8 had naïve views on the relationship between science and economics. She thought that science is not related to economics, as shown in the excerpt below:

Science is not related to economics because they do not work together (P8, pre)

After engaging in the first set of activities (Q1) in the context of climate change, P8 still was not able to relate science and economics. She thought that science is not associated with financial issues, as shown in the excerpt below:

> *Science is not related to economics because economics is related to money. Science is not related to these (P8, Q1)*

Engaging in the second set of activities (Q2) in the context of electromagnetic wave pollution allowed P8 to develop informed views on the relationship between science and economics. She explained that, financially, dentists might be affected negatively because when fluoridated water, which reduced tooth cavity, becomes available to the society publicly, the dentists might have fewer patients to cure and consult. Therefore, she suggested selling fluoridated water through the dentists so that they control the amount of fluoride intake and keep on profiting, as shown in the excerpt below:

> *Yes, because if it [fluoridated water] can be sold anywhere, dentists will lose a lot of money. The dentists are curing the tooth cavity and they are consulting their patients to remove the tooth cavity. They give their patients medications or toothpaste. It is better not to sell it in public places, and only the dentist will sell them, or the dentists make it for them better than taking them improperly. They will decide the amount of fluorine they are going to put so that people to no intake the wrong dosage. They will give them more information other than what people know (P8, Q2)*

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P8 showed informed views on the relationship between science and economics. In this context, she explained that buying technological devices costs people a lot of money. As the electromagnetic waves emitted from technological devices cause diseases, people might waste their money because they are buying harmful devices. On the other hand, people who are in charge of selling technological devices profit financially, as shown in the excerpt below:

> *Products created by science may have positive and negative effects on people. They [scientists] want to sell technology, and they [people] are buying and in another way the people are buying diseases and sickness. So in both ways it is harmful technology harmful. It is a bit of waste of money to buy things that cause diseases and may harm you. Scientists are benefiting from this thing. Technology can help us in different ways and could harm us in different ways (P8, Q3)*

In the context of animal testing, after engaging in the fourth set of activities, P8 did not elaborate on her answer and showed intermediary views about the relationship between science and economics. She thought that science is related to economics because humans spend money on medication resulted from animal testing, which is a scientific experiment, as shown in the excerpt below:

> *Humans might buy medicines from animals that have experienced animal testing (P8, Q4)*

Analysis of responses of the post-test showed that P8 had developed informed views on the relationship between science and economics. She showed more than one informed views to explain how science and economics are related to each other. She claimed that science is related to economics because the products sold in the markets are created by science. She elaborated, suggesting that people make money by selling these products, such as medications, in pharmacies. Moreover, she stated that the prices of scientific products should be studied carefully. She thought that when scientific products have expensive, people can't afford it. However, if they are cheap, people might afford it and use it in larger amounts that might, in turn, cause diseases. She thought that medications should be available to the public through doctors and pharmacists to control the amount of medication that people intake to prevent over dosage, as shown in the excerpt below:

> *They [scientists] are discovering medicines that are getting sold. It might be very expensive or it might be very cheap. If it is expensive not a lot of people could afford it, and if it is cheap a lot of people can't afford it and if a lot of people can afford it anyone could buy it, and it wouldn't really have affected negatively. Not to make it cheap enough so that people would buy it so that no one gets hurt or gets a mistake in dosage. Only specific places like hospitals, pharmacies, or doctors provide it so that they know that people accidentally don't take the wrong food like the golden rice. So they will not really affect a person. They will buy it just because it is cheap and they will eat it, and they will have negative effects. Fluoridation and genetically modified food that they sell it in the supermarkets should be stored by the doctors workplaces and pharmacies and not in the public places where anyone can go and buy cures for undiscovered diseases without knowing how much to take. Doctors need to give them because people maybe couldn't differentiate between normal and golden rice and they do not to eat it just to try it because this will definitely affect eye doctors (P8, post)*

Participant 22. In the pre-test, analysis of responses, the question that aimed to assess participants' views on the relationship between science and economics indicated that P22 did not respond to the question about this theme. Nevertheless, engaging in the first set of activities (Q1), in the context of climate change, already allowed P22 to develop informed views on the relationship between science and economics. She thought that factories, which emit greenhouse gases and cause pollution, might close to reduce environmental problems. Under these circumstances, she thought that people face financial difficulties as they lose their jobs. On a larger scope, P22 claimed that countries face an economic crisis if industries are reduced due to the tendency of reducing pollution, as shown in the excerpt below:

> *The workers, for example, they want to buy something they don't have money so they can't really buy stuff and the people who are selling will also not have money because they are not selling so the whole country will not have money (P22, Q1)*

After engaging in the second set of activities (Q2) in the context of water fluoridation, P22 showed similar informed views to relate science and economics. She explained that many people, like dentists, might lose their jobs when people use certain scientific products, such as fluoridated water. Moreover, she thought that the country's economic stability is affected negatively when the unemployment rate increases. In this case, she assumed that countries ask for the financial support of certain organizations to maintain economic stability and keep the reputation of the country high, as shown in the excerpt below:

It affects the economy since if the answer is that of model A. Dentists will lose their jobs. If the answer is that of model B, the people that put fluoride in water will lose their jobs. Either way, the country will become weaker, or politicians will ask for money and help from organizations (P22, Q2)

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P22 was able to show informed views on the relationship between science and economics. She explained that when scientists prove that electromagnetic waves cause cancer, companies that make and sell electronic devices will be bankrupt and will face financial problems, as their products are not sold at the same rate. The decisions made by the government regarding scientific issues may influence the economy of the country. Moreover, to related science to economics, she claimed that some people prioritize the financial benefits and support the claim that keeps them profiting financially, as shown in the excerpt below:

Maybe scientists want to protect their job, for example, people making technology if they decided that model A is correct then the technology will be less, and they won't get as much money, but if model B is correct they will still have their jobs, but it is not helping people with their money and staff, so they are trying to support specific models because they don't want to lose their jobs and they want money. Also because if they made a decision in the end about model A or model B, it affects the decision of making less technology or even stopping it, or they keep it going on if model B is the answer. If they produce more the people will buy then, and the people will pay so they would have more money, but if they stop the economy will be low in the country, and they won't have money a lot (P22, Q3)

In the context of animal testing, after engaging in the fourth set of activities (Q4), P22 showed intermediary views to related science and economics. She claimed that if animal testing is replaced by technology, some people, who work in animal testing labs, might lose their jobs and face financial problems as shown in the excerpt below:

> *People whose job is to test on animals they are going to lose their job if they decide if the model is the answer so they will lose their jobs and try to support model A so that they don't lose their jobs (P22, Q4)*

Analysis of the post-test indicated that P22 had developed informed views to explain the relationship between science and economics. She thought that scientists support certain viewpoints based on their financial benefits. She claimed that science is related to economics because the productions of certain products created by science might cause pollution or diseases. In turn, this might result in a reduction of factories that manufacture these products. When factories close to reduce pollution, some people lose money. Consequently, the unemployment rate increases in the country, as illustrated in the excerpt below:

> *Sometimes people support different ideas because they want money. They don't want to lose their jobs; they just want to save their jobs. For example, the water fluoridation dentist wouldn't support it because if people would buy fluoridated water, then they will stop going to the dentist because people go to the dentist to get fluoride in their teeth. But if they get fluoridated water they want to go to the dentist anymore so the dentist will not get the money as much, that's why he will not be supporting the idea of water fluoridation (P22, post)*

Relationship between science and social organizations. Referring to Table 11, analysis of the responses of the pre-test showed that out of the sixteen participants, fifteen participants did not answer the question regarding the relationship of science and social organizations, while only one participant had naïve views regarding the relationship of science and social organizations. None of the participants showed informed views on the relationship between science and social organizations. On the other hand, analysis of the responses of the post-test showed that only two participants did not respond to the question, while four showed intermediary views when relating social organizations to science (Table 11). Moreover, the number of participants showing informed views increased sharply in the post-test. More than half of the participants (62.5 %) were capable of providing informed views on the relationship between science and social organizations. Below please find the detailed analysis of responses of three randomly selected participants to the question that aimed to assess their views of the relationship of science and social organizations.

Participant 5. Analysis of the responses of the pre-test showed that similar to the vast majority of the participants, P5 did not answer the question that assessed participants' views on the relationship between science and social organizations. After engaging in the first set of activities (Q1) in the context of climate change, P5 showed intermediary views on the relationship between science and social organizations. He claimed that social organizations influence the actions of people and governments. Moreover, he thought that social organizations convince people and politicians to be more responsible in their actions regarding decreasing pollution and taking care of the environment, as shown in the excerpt below:

They can convince the people and the government or politically wise people to care about our earth and try to convince other people to protect the earth and reduce pollution (P5, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P5 already developed informed views on the relationship between science and social organizations. He claimed that social organizations influence the decisions made by the government and convince them to act in a certain way. Moreover, he also stated that social organizations work on giving choices to the people in the society regarding the consumption of scientific products, as shown in the excerpt below:

They would convince society and the governments by not adding fluorine. Their role is to convince everyone to have a choice and let the people have a choice. That is, they make water bottles without fluorine and water bottles with fluorine for people to choose (P5, Q2)

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P5 also showed informed views to relate science to social organizations. He thought that social organizations influence the opinions of the politicians, scientists, and people in society. Moreover, social organizations work to raise awareness and convince them to come up with solutions regarding problems created by science, as shown in the excerpt below:

Basically, [social organizations work on] convincing as much as they can everyone. Government Society scientist or maybe write articles and try to make them realize and convince everyone to come up with a solution (P5, Q3)

After engaging in the fourth set of activities (Q4) in the context of animal testing, P5 gave more than one informed view to explain how science and social organizations are related. He claimed that social organizations protect the animals in debates about animal testing and highlight the ethical considerations related to animal testing. They show emotional videos and write articles about how people harm animals to strengthen their argument. Moreover, he thought that they influence people and government by organizing protests against those who support animal testing, as shown in the excerpt below:

> *Social organizations protect animals and try to convince governments to replace animal testing with technology. Obviously, they want to support the animals. Tries to convince the government as I said to develop technology and reduce animal testing it's so sad how they are harming the animals and how can it lead to extinction, then they want to convince everyone to build based on evidence 6 and 4. They are influencing the society to Protest the government against the position or against the position of the government and to really convince everyone that is really not ethical (P5, Q4)*

Analysis of the responses of the post-test indicated that P5 had developed informed views on the relationship between science and social organizations. He thought that social organizations support a cause or an idea, try to convince people with their opinion by showing them evidence collected from research studies. Moreover, he claimed that social organizations trigger people to protest and convince the government to act in a certain manner regarding a scientific issue, as shown in the excerpt below:

[Social organizations try] to support one idea and try to convince everyone about their opinion by evidence and research they would convince the society will protest to convince the government economic wise to reduce the carbon dioxide for example (P5, Post)

Participant 8. Analysis of responses of the pretest showed that P8 did not respond to the question on the relationship between science and social organizations. However, the answers to the questions in the first set of activities (Q1) indicated that P8 developed intermediary views on science and social organizations' relationships. The views suggested by P8 indicated that the relationship between science and social organizations was limited in contributing to environmental issues. She thought that social organizations are related to science because many of them target environmental issues. That is, she stated that social organizations might work with scientists to solve certain environmental issues, as shown in the excerpt below:

These social organizations sometimes talk about the planet earth and the environment. They [social organizations and scientists] can work together to make the world a better place (P8, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P8 already developed informed views on the relationship between science and social organizations. She claimed that social and health organizations support certain causes and rights. Social organizations, such as WHO and dental associations, consider the influence of scientific products and contribute to improving the conditions regarding scientific issues as shown in the excerpt below:

Social organizations will decide because there are social organizations that are for dentists; for example, there are associations… dental associations or others like UN associations related to people's health ... they connect… they are definitely are contributing (Q2)

P8 continued showing informed views when she was asked to related science and social organizations after engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution. She claimed that social organizations suggest solutions to certain problems, and they give opportunities for people to agree on certain ways of solving a problem related to the production of scientific products as shown in the excerpt below:

There are organizations to fix this problem by how do they sell it what do they sell there are organizations I guess that do things like this like cures like curing and technology and issues like this, so they decide with the society how they want to sell it like how they want the people to use it how they are going to need it (P8, Q3)

After engaging in the fourth set of activities (Q4) in the context of animal testing, P8 showed several informed views to relate science and social organizations. She claimed that social organizations try to stop performing animal testing. She explained that they raise awareness about ways of protecting animals and communicate with scientists to convince them to replace animal testing with advanced technology, as shown in the excerpt below:

I feel like social organization like animals they say how to take care and how to test this type of problem case social organizations like communicate with the *scientists and say that it is a bad thing you don't have to sell it even if nothing has happened to the animal and you may sell it they need to stop scientists to do animal testing maybe they have the animal, but they didn't see that something that benefits our body and how much advance is the technology now they can show what is happening inside the body of the animal (P8, Q4)*

Analysis of the responses of the post-test indicated that P8 had several informed views on the relationship between science and social organizations. First, she stated that social organizations convince people with certain views by showing evidence and data discovered by scientists. Moreover, she claimed that social organizations protect people's rights and demand from the government their needs. She mentioned that they organize voting campaigns so that people vote and support their opinion. They work on making people satisfied with their needs and have what they deserve, as shown in the excerpt below:

Sometimes the society should not be convinced. They should see how the people are thinking of it. They really see what could happen, for example, if I think of something that society should tell if that could help all of the people, so they will stay that this population here more convincing to what we really need to do and they do, and this population will be happy with it and satisfied with it. Showing them how did they work to show them how they found that this is the way to protect blindness, so they will show them how can they work. They [scientists] show them how they found the data and the evidence. They, of course, work with society, so that they help the society to show the products and how they are working so that the scientists and the government will convince society. Making people's opinions protected by society and make things how people wanted to be *like through voting. The people will vote, and they will see the highest score. People will see that they are deserving of this and the society is following, and they will feel like their opinion in the place where they live is really protected (P8, post)*

Participant 22. Analysis of the responses of the pre-test indicated that P22 did not answer the question that aimed to assess participants' views on the relationship between science and social organization, similar to the rest of the participants. However, engaging in the first set of activities (Q1) in the context of climate change already allowed P22 to develop informed views when describing the relationship between science and social organizations. She already showed awareness that social organizations spread awareness by organizing campaigns so that people change their behavior. They persuade people to stop producing gases and polluting the Earth. Moreover, she thought that social organizations collaborate with the government regarding actions to be taken in the country. She considered that social organizations and governments often disagree and try to compromise, as shown in the excerpt below:

Politicians and the government and the organizations have to agree what they want to do to the country and they also might fight about stuff, but they need to like find an answer to do something like campaigns to find solutions for the country (P22, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P22 also showed informed views on the relationship between science and social organizations. She restated that social organizations raise awareness, organize campaigns, and work with the government to find solutions to specific social issues.

Moreover, she claimed that they work to give people the option of choosing the type of water they want to drink so that debates/protest regarding these issues do not take place as shown in the excerpt below:

> *They can make water that is without fluoride ... that way the society will have options … and the politicians will not fight. Each person will have what they want because some people want fluoride and some people don't. So now they have options they can choose what they want to drink. They cooperate with them like they make ideas about what they want to do to the country, think of campaigns; they also like to work together for the society of the country. They work together to know what society needs and what should they do (P22, Q2)*

The answers to the question on the relationship between science and social organizations in the third set of activities (Q3) showed that P22 repeated the previously informed views. She thought again that social organizations raise awareness and contribute to finding solutions to social issues, as shown in the excerpt below:

> *They [social organizations] can raise awareness and maybe suggest to make machines that takes away some of the electromagnetic waves (P22, Q3)*

After engaging in the fourth set of activities (Q4) in the context of animal testing, P22 related science and social organizations by focusing on raising awareness that aim to change the mindset of people about scientific issues, as well as on organizing protests to drive them to ask replacing animal testing with technology as shown in the excerpt below:

They [social organizations] will change the human mindset. For example, participant number 9 first was supporting model A, and when he heard other people's opinions, he *changed his mind and realized that model B is correct. They can spread awareness, they can help by asking people, and if everyone agrees they can make some technology, they can test on this technology instead of the animal, and it will be accurate. They should protest and give ideas (P22, Q4)*

Analysis of the responses of the protest showed that P22 kept showing informed views on the relationship between science and social organizations. She mentioned more than an informed idea to related science to social organizations. She claimed that social organizations spread awareness to help the government to find solutions regarding social problems so that people are satisfied in the society. Moreover, she thought that they influence the opinion of the people regarding scientific issues. Finally, she stated that they organize fundraising to protect animals, as shown in the excerpt below:

> *They [social organizations] spread awareness and help the government. They also might make things to solve problems. They can help solve the problem; for example, for the electromagnetic waves, they can come up with ideas with machines that can help. They can spread awareness. They can talk to the people, and maybe those people are good at making machines so they can work together with the society to make the machines. They tried to change the opinions of the people. For example, animal testing a lot of people are making websites and spreading awareness for people. Some are doing big sales to collect money for the animals like it is fundraising for animal testing. They were just trying to spread awareness, so people stop thinking badly. For example, it is kind of like in our class; we were trying to convince P9 that animal testing is not really good for the animals. And after eating all the opinions, he changed his opinion. This*

is what social organizations try to do. They tried to change other people's opinions. They tried to help the society to solve the problem; for example, for animal testing, they might tell people that they should test on samples of humans and not the whole body. That will be more accurate and will not harm anyone. So they will give ideas to solve the problems so that everyone will be satisfied with the solution (P22, post)

Ethical issues in science. Analysis of the responses of the pretest that aimed to assess participants' views regarding the ethical issues in science indicated that none of the participants answered the question. After engaging in the first set of activities (Q1), still, none of the participants was able to develop views regarding ethical issues in science. Only after engaging in the second set of activities (Q2) in the context of water fluoridation, the participants started to express their views regarding the ethical issues related to science. Analysis of the responses of the second set of activities showed that none of the participants had naïve views. The majority of the participants (75%) developed intermediary views regarding the ethical issues in science (Table 12). After engaging in the second set of activities, three participants (18.7 %) already developed informed views regarding the ethical issues in science. Analysis of the following sets of activities (Q3 and Q4) showed an increase in the number of participants who had informed views of the ethical issues in science to 31.2% and 56.2%, respectively (Table 12). On the other hand, the number of participants having intermediary views decreased to 68.7% and 12.2%, respectively. However, the analysis of responses of the posttest revealed that none of the participants had informed views of ethical issues in science. Only four participants (25%) showed intermediary views, while the rest of the participants did not respond to the question regarding the ethical issues in science.

Below please find the detailed analysis of responses of three randomly selected participants to the question that aimed to assess their views of ethical issues in science.

Participant 5. Similar to the rest of the participants, P5 did not respond to the question regarding the ethical issues in science in both the pretest and after the first set of activities (Q1). Only after engaging in the second set of activities (Q2) in the context of water fluoridation, P5 developed intermediary views regarding the ethical issues in science. He considered that giving medications to people without asking their permission and without making them aware of the process is unethical. He thought that people need to be fully aware of their intake of fluorine, especially that it has the risk of causing health problems. P5 suggested giving choices to people by making different types of water to be available to them, as shown in the excerpt below:

> *It is not ethical since we are forcing people to take medication without knowing, and this may cause them health problems. My solution will be to have bottles that have more fluorine and water bottles with no fluorine because depending on the body type (P5, Q2)*

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P5 considered that forcing people to be exposed to electromagnetic waves is unethical. He mentioned that even if people take precautions to avoid being exposed to electromagnetic waves, they could not control and stop their exposure to electromagnetic waves because their surroundings are polluted with electromagnetic waves. P5 suggested reducing electromagnetic wave emission as much as possible, as shown in the excerpt below:

It is not ethical to force people to get exposed to electromagnetic waves, which cause diseases, especially when they do not want to get exposed to it. The solution may be to lower the radiation as much as possible so that no one would get harmed OP5, Q3)

After engaging in the fourth set of activities (Q4) in the context of animal testing, P5 was able to develop informed views of the ethical issues in science. He provided more than one informed idea to describe ethical considerations in science. P5 considered that harming animals to provide medical benefits to people is unethical, especially when there are several methods like technology that can replace animal testing. P5 also found that putting people at risk of getting harmful medication because of experimental error is unethical, as shown in the excerpt below:

It is not ethical to try medication on animals, get different results than trying it on humans, and harm humans because of the experimental errors. It is not ethical to harm the animals which are necessary for humans; there are many ways to test medication, not on animals we can use technology. No, it is not ethical to harm the animals that are necessary for the humans there are many ways to test medication, not on animals we can use technology (P5, Q4)

In the posttest, P5 showed intermediary views of ethical issues in science. He suggested views that limited ethical issues in science to forcing people to intake or get exposed to scientific products that are harmful to people, as shown in the excerpt below:

… That we don't force the society to take the medication and not knowing the side effects (P5, post)

Participants 8. Analysis of the responses showed that P8 did not respond to the question regarding the ethical issues in science in both the pretest and after the first set of activities (Q1). However, after engaging in the second set of activities (Q2) in the context of water fluoridation, P8 developed informed views regarding the ethical issues in science. She considered that forcing people to drink fluoridated water, which may be unhealthy, is unethical. She thought that if people do not want to reduce cavities through water fluoridation, they should have the choice of reducing cavities in alternative ways suggested by the dentists. She thought that people should not be forced to do what they do not want to do, as shown in the excerpt below:

> *It is not ethical since people don't want to drink it, so basically, they are forced by the society. If dentists want to remove a cavity, they can ask if they want to drink the water or they remove it. It is not really healthy. You can find another solution another thing to remove the tooth cavity easily instead of fluorine. They might really harm us. They will be forcing people to take it. Everyone wouldn't be really forced something that they don't want. (P8, Q2)*

In the context of electromagnetic wave pollution, after engaging in the third set of activities (Q3), P8 considered that forcefully exposing people to electromagnetic waves is unethical, similar to the previous response. Besides, P8 thought that emission of electromagnetic was is not worth putting people's lives at risk is unethical, as shown in the excerpt below:

> *It is not ethical to expose people to electromagnetic waves because it is dangerous, and it is not worthy of having cancer. However, people are forcefully exposed to electromagnetic waves (P8, Q3)*

After engaging in the fourth set of activities (Q4) in the context of animal testing, P8 claimed that harming animals is unethical because animals have feelings and get hurt just as humans do. It is unethical to harm animals. She suggests replacing animal testing with advanced technology. It is not ethical to put people at risk of getting the wrong medication because sometimes, animal testing does not provide accurate results. It is essential to make sure that the tests performed on animals do not harm the animals, as shown in the excerpt below:

So it is very wrong to do [animal testing] because animals are like humans. They also have feelings that would hurt them. Maybe in both ways, it would harm both animals and humans. We can use technology or animals that are not really useful to us like mice. It is a really bad thing to her and the animals, but at least we need to be sure that the thing that we are using the animal for or harming this animal (P8, Q4)

Finally, the analysis of the post-test showed that P8 did not respond to the question regarding the ethical issues in science.

Participant 22. Similar to the rest of the participants, P22 did not respond to the questions regarding the ethical issues of science in both the pretest and the first set of activities (Q1), which was in the context of climate change. After engaging in the second set of activities (Q2), P22 already expressed informed views of the ethical issues in science. She thought that it is unethical to force people to intake chemicals/medication when they do not want to. She considered that people should have the right to choose which kind of water they want to drink, as shown in the excerpt below:

It is not ethical to put fluoride in water since it is forcing society to drink it. It is more ethical to give the people a variety; they people that want fluoride to get it and people that don't do not get it (P22, Q2)

After engaging in the third set of activities (Q3), P22 showed intermediary views that considered ethical issues in science are limited to exposing people to electromagnetic waves and unwillingly developing diseases. She explained that people are forced to be exposed to electromagnetic waves of phones and computers without even being aware of their exposure, as shown in the excerpt below:

They are still getting waves from other people. Maybe people that support model A they try to turn off their phones and their routers and everything, but actually, there are the neighbors, and everyone that has the things on, and the electromagnetic waves are coming from outside. SO it is not their decision if they want to be exposed or not. That is not ethical (P22, Q3)

Analysis of responses of the fourth set of the activities (Q4) indicated that P22 had several informed views regarding the ethical issues in science. She mentioned that animal testing is unethical because animals are forcefully participating in experiments and getting harmed without having any choice. She considered that it is immoral for people to see animals' sufferings and have a careless attitude, as shown in the excerpt below:

People are the ones that are testing the animal. The scientists are testing on the animals for the people. They shouldn't do that the people who are testing animals and seeing how much they are suffering and that they don't care. Some people don't want to test on animals, and they don't want animals to die on *which they tested. But the people who are testing on animals like the animals are forced to be tested on like they cannot choose (P22, Q4)*

Finally, in the posttest, P22 did not respond to the question regarding the ethical issues in science.

Profile Summaries of Participants 5, 8 and 22

The following section provides a summary of the profiles derived from the detailed analysis of responses provided by participants 5, 8, and 22. The detailed analysis of responses and the preparation of the profiles allowed the researcher to identify commonalities among the changes in the participants' NOS views and helped her to discover the patterns regarding variations of NOS views in similar contexts. As the researcher randomly selected three participants to analyze their responses in detail, a few extreme cases apparent in the profiles of these participants were represented in the section of analysis of NOS views by all participants.

Participant 5 (P5). The detailed analysis of responses of participant 5 showed that this participant did not express any naïve view at the beginning, throughout, and at the end of the study. The pretest results showed that P5 had intermediary views of all the ten themes of NOS except on ethical issues in science. Engaging in the first set of activities in the context of climate change was enough for P5 to develop informed views of the tentativeness of scientific knowledge, differences in views, scientific practices and knowledge construction, the relationship of science and society, and the relationship of science and social organizations. P5 was able to develop informed views of the tentativeness of personal explanations in science and the validity of information only after engaging in the second set of activities in the context of water fluoridation.

On the other hand, he showed informed views of the relationship between science and politics only after engaging in the third set of activities in the context of electromagnetic wave pollution. Similar to most of the other participants, P5 did not respond to the question regarding the ethical issues in science in the pretest and Q1 questionnaire. Engaging in the second set of activities (Q2) allowed him to show intermediary views of this theme. P5 showed informed views of the ethical issues in science only in the context of animal testing. His views regarding the ethical issues in science changed in the posttest as he showed intermediary views. Throughout the study, P5 kept on showing informed views regarding the ten themes with no variations except in the themes of the tentativeness of scientific knowledge and relationship of science and politics, which changed in the context of animal testing as he showed intermediary views.

Participant 8.(P8).The detailed analysis of responses of participant 8 showed that engaging in the first set of activities (Q1) in the context of animal testing was enough to develop her intermediary views of the tentativeness of scientific knowledge, tentativeness of personal explanations in science, differences in views, validity of information and the relationship of science and society into informed views without any variations throughout the study. P8's naïve views of the scientific practices and knowledge construction, the relationship between science, politics, economics, and social organizations developed incrementally. Engaging in the first set of activities (Q1) allowed P8 to develop intermediary views regarding these themes. Only after engaging in the second set of activities (Q2) in the context of water fluoridation, P8 was able to develop informed views. Similar to the rest of the participants, P8 did not respond to the question regarding the ethical issues in science in the pretest and Q1 questionnaire.

However, engaging in the second set of activities (Q2) in the context of water fluoridation allowed her to develop informed views of this theme. Her informed views only changed in the posttest as she showed intermediary views of ethical issues in science in the posttest. P8 showed changes in her views regarding scientific practices and knowledge construction and the relationship of science and economics in the context of animal testing (Q4), while changes in views regarding the validity of information and ethical issues in science reveals in the posttest.

Participant 22 (P22). The detailed analysis of the responses of participant 22 showed that she already had informed views of differences in views before engaging in the activities. P22 continued showing informed views of the differences in views throughout the research study with no variations in context. The detailed analysis also indicated that after engaging in the first set of activities (Q1) in the context of climate change, P22 already developed informed views of the relationship of science with politics, economics, and social organizations after showing naïve views in the pretest. P22's views regarding the relationship between science and social organizations did not change in different contexts. However, her views regarding the relationship of science with politics and economics showed changes in the context of electromagnetic wave pollution and animal testing, respectively. The analysis also showed that engaging in the first set of activities (Q1) allowed P22 to develop her intermediary views of the tentativeness of personal explanations in science, the validity of information, the relationship of science and society into informed views. P22 showed no changes in her views except regarding the validity of information in the posttest. Engaging in the second set of activities (Q2) allowed the development of P22's intermediary views regarding the tentativeness of scientific knowledge and scientific practices and knowledge construction into informed views without any variation in contexts. Similar to the rest of the participants, P22 did not have any opinions regarding the ethical issues in science in the pretest and the first set of activities (Q1). After engaging in the second set of activities (Q2), P22 showed informed views of the ethical issues in science. These views varied in the posttest as P22 showed intermediary views.

Summary of Changes in the NOS Views

Analysis of changes in NOS views for the whole class and by participants indicated that, after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues, more participants developed informed views of the ten themes of NOS targeted in this research study. In the pre-test, the participants were not able to provide informed views of the tentativeness of personal explanations in science, the validity of information, scientific practices and knowledge construction. Moreover, the participants in the pre-test were not able to relate science to society, politics, economics, social organizations and ethical issues in science. Throughout the research study, most of the participants gradually developed more informed views of the ten NOS themes. In the post-test, more than the of the participants showed informed views of the tentativeness of scientific knowledge (62.5%), differences in views (87.5%), scientific practices and knowledge construction (75%), the relationship of science and society (56.2%), politics (50%), economics (62.5%) and social organizations (62.5%) (Table13). However, even though most of the participants showed informed views of the ethical issues in science after engaging in the second, third and the fourth sets of activities, the participants were unable to provide informed views of this theme in the posttest.

Table 14 provides the averages of participants' NOS views across the ten targeted themes in the posttest. Analysis of the data in this table results shows that after engaging in four sets of activities 9.37 % of the participants showed naïve views in the posttest, while 34.37 % and 51.87% of the participants who responded to the questions showed intermediary and informed vies of NOS, respectively. The rest of the participants did not respond to the questions of the posttest. At the end of the research study,, on average, almost half of the participants provided informed views of the ten themes of NOS in the post-test.

Analysis of Table 14 shows that there was a steady increase in the informed views of participants in 7 out of the ten targeted themes (Tentative scientific knowledge, differences in views, scientific knowledge construction, relationship between science and society, relationship between and politics, relationship between science and economics, relationship between science and social organizations). However, for two themes, Tentative personal explanations and validity of information), views of all participants 'changed to intermediary, while the views of a portion of the participants changed to informed. Finally, for the theme "ethical issues in science the majority of participants stayed at the naïve level

Table 13

Frequency Distribution and Percentages of Students' Views of Target Nature of Science Themes

FRA Wheel Category	Tentative Scientific knowledge		Tentative Personal Explanations		Validity of Information		Differences in Views		Scientific Knowledge Construction	
(N=16)	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Naïve	4 (25 %)	0 (0%)	7 (43.7 %)	0 (0%)	0 (0 %)	0 (0%)	6 (37.5%)	0 (0%)	7 (43.7%)	0 (0 %)
Intermediary	9 (56.2%)	6 (37.5%)	7 (43.7%)	10 (62.5%)	12 (75 %)	12 (75%)	8 (50 %)	2 (12.5 %)	8 (50 %)	3 (18.7%)
Informed	2 (12.5%)	10 (62.5%)	0 (0%)	6 (37.5%)	0 (0)%	4 (25%)	1 (6.2 %)	14 (87.5%)	0 (0 %)	12 (75%)

FRA Wheel Category	Relationship between Science and Society		Relationship between Science and Politics		Relationship between Science and Economics		Relationship between Science and Social Organizations		Ethical Issues in Science	
(N=16)	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Naïve	5 (31.2 %)	1 (6.2 %)	6 (37.5 %)	0 (0 %)	5 (31.2 %)	2 (12.5 %)	1 (6.2%)	0 (0 %)	0 (0 %)	12 (75%)
Intermedia	8 (50 %)	6 (37.5%)	2 (12.5 %)	4 (25%)	1 (6.2 %)	4 (25%)	0 (0 %)	4 (25%)	0 (0 %)	4 (25%)
Informed	0 (0%)	9 (56.2%)	0 (0%)	8 (50 %)	0 (0%)	10 (62.5%)	0 (0%)	10 (62.5%)	0 (0%)	0 (0%)

Table 14

Frequency Distribution, Percentages and Average of Students' Views of Target Nature of Science Themes in the Posttest

FRA Wheel Category	Tentative Scientific knowledge	Tentative Personal Explanations	Validity of Information	Differences in Views	Scientific Knowledge Construction	Relationship between Science and Society	Relationship between Science and Politics	Relationship between Science and Economics	Relationship between Science and Social Organizations	Ethical Issues in Science	% Avg
(N=16)	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	
Naïve	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0 %)	1 (6.2 %)	0 (0 %)	2 (12.5 %)	0 (0 %)	12(75%)	9.37
Intermediary	6 (37.5%)	10 (62.5%)	12 (75%)	2 (12.5 %)	3 (18.7%)	6 (37.5%)	4 (25%)	4 (25%)	4 (25%)	4 (25%)	34.37
Informed	10(62.5%)	6 (37.5%)	4 (25%)	14 (87.5%)	12 (75%)	9 (56.2%)	8 (50 %)	10 (62.5%)	10 (62.5%)	0 (0%)	51.87
Total											95.61

1. Post: Post-test
2. The total number of participants may not be 16 as the participants, who did not respond to the question, were excluded.
3. The total % is not 100% because 4.39% of the participants did not respond

Part 2: Changes in the Argumentation Skills

At the beginning of the intervention, the teacher introduced to the participants three components of argumentation (claim, evidence, and counterargument) referring to Toulmin's model of argumentation. Then, the participants engaged in four sets of activities (Q1, Q2, Q3, and A4) in four controversial social issues that were targeted in this research study (climate change, water fluoridation, electromagnetic wave pollution, and animal testing). In each of the sets of activities, the participants evaluated the credibility of the websites that represented different views regarding the four social controversial issues in terms of currency and accuracy. In each of these contexts, after reading and familiarizing themselves with the socio-scientific controversial issue, the participants completed MEL diagrams by coordinating lines of evidence (supporting the model, strongly supporting the model, contradicting with the model and having nothing to do with the claim) with Models, which are general claims about a specific controversial socio-scientific issue. In addition the participants reflected on the argumentation components in the context of the controversial social scientific issues. Following the evaluation practices and the completion of the MEL diagrams, the participants engaged in reflective discussions about four socio-scientific controversial issues. After engaging in reflective discussions, the participants were asked to respond to the MEL-diagram questionnaires and to formulate arguments and counterarguments regarding each of the controversial issues. These questions particularly tracked the changes in the participants' ability to formulating arguments and counterarguments throughout the research study.

The following section presents the analysis of the changes in the participants' argumentation skills about the four social controversial issues that were targeted in this research study. The researcher used the FRA framework to analyze the data on argumentation. This analysis provides the changes in students' arguments and counterarguments in the pre-test in the post-test and the four sets of activities (Q1, Q2, Q3, and Q4). The ability of participants in formulating arguments and counterarguments in the pre-test and post-test was assessed in the context of genetically modified food. GMF was selected as a context for the pre-test and post-test because the participants were familiar with the topic as it was discussed in more detailed during the previous biology sessions.

The two components of argumentation that were emphasized in this research study were the development of arguments and counterarguments. An argument is a set of reasons that supports a specific idea or position. A counterargument is an argument that challenges the initial argument. It expresses the view of a person who disagrees with one's position. Participants' responses for each component (an argument and a counterargument) were analyzed according to the following categories, which were adapted from Mason and Scirica (2006):

Level 1: no justification or invalid justification.

Level 2: valid justification supported by one reason.

Level 3: valid justification supported by more than one reason.

Analysis of changes in arguments for the whole class.

The following section provides the analysis of changes in the participants' ability to formulate arguments as a whole class. It provides examples of responses from each level of argumentation in the pretest, posttest, and each of the contexts of social-controversial issues.

Pre-test: Genetically modified food. As shown in Table 15, analysis of the responses to the pre-test indicated that, in the context of GMF, out of sixteen participants, the arguments of two participants (12.5 %) were classified as Level 1 because they either did not give a justification or gave an invalid justification to support their argument regarding the production of GMF, as seen in the excerpt below:

Yes, people can try this golden rice (P4, pre)

On the other hand, analysis of responses of the pre-test indicated that the majority of the participants (75%) formulated Level 2 arguments in the pre-test. These participants provided only one reason to support their justification to support their argument regarding the production of GMF. Participants who supported the production of GMFs considered that GMFs might prevent blindness. While, participants, who opposed the production of GMFs, mentioned that GMFs might be unhealthy as shown in the excerpts below:

No. because I think changing in food's genes is not healthy (P11, pre)

Yes, because this could help a lot of people who suffer from blindness (P12, pre)

Only two participants formulated Level-3 arguments in the pre-test. These participants gave two or more reasons to support their justifications regarding the production and consumption of GMF. Besides mentioning that GMFs might be unhealthy, they claimed that biomedical tests are not performed to ensure the safety of GMF and errors might result if the effect of GMFs on people's health is not thoroughly studied. Therefore, GMFs should not be sold before ensuring their safety. Moreover, they considered that having a healthy diet is enough for preventing Vitamin A deficiency, as shown in the excerpts below:

No [GMF should not be produced and consumed], because it (GMF) is not approved by scientists and might be dangerous … because they might do something wrong with the genes and not realize. It is still not created, and no one really specified how it really works and how many to take as an amount (P8, pre)

They should not produce and sell golden rice to anyone before testing everything so that it will be secure, and everyone takes it and makes sure there are no side effects. Because there is no need for modifying a thing if it already has its benefits*, it* is *all about humans' health. It's better to be patient and take normal vitamins and have a healthy diet (P5, pre)*

Context-1: Climate change. After engaging in the first set of activities (Q1) in the context of climate change, analysis of responses indicated that one participant did not answer the question that aimed to assess participants' ability to formulate arguments regarding the causes of climate change. Moreover, analysis of responses also demonstrated that more participants (25 %) formulated Level 1 arguments to support their justification (Table 15). These participants did not provide any justification and but they just repeated the claim that was already provided in the models, as seen in the excerpts below:

I support model A because in my view humans are causing it not the sun (P11, Q1)

I support model B because it is caused by the Sun (P21, Q1)

`The number of participants formulating Level-2 arguments decreased from 75% to 43.7 % after engaging in the first set of activities (Q1) (Table 15). Many of these participants argued that climate change is caused by human activities (Model A) because the evidence provided to support this justification is more robust and current, as seen in the excerpt below:

I support Model A firstly because the evidence strongly supports the model like the other one was not very strong the evidence. Also, it is more current because that is what is happening now, so that is more current. Everybody knows that human activities are releasing lots of gases, so that's why yes because that is what is happening now, so that is more current (P22, Q1)

I think that climate change is because of human activities and I support Model A because model A had more supportive evidence than model B and no evidence completely supports model B (P19, Q1)

Another participant considered that climate change is due to human activities because changes in the solar system are not visible. Moreover, he stated that people could recognize that climate change is due to the increase in pollution because of human activities, as shown in the excerpt below:

Model A because of human activities because human activities include polluted air and let climate change be worse. All people can see it is happening, but model B maybe the scientists may not see the truth in the solar system. (P16, Q1)

One participant mentioned that human activities are more influential on the climate than the changes occurring in space, as seen in the excerpt below:

I support model A more than mode B. Human activities can cause more climate change. I support my position by examples of human activities that people do in their daily lives and harm. The human activities are affecting more, and their [humans] actions are more (P4, Q1)

On the contrary, as shown in Table 15, analysis of responses of questions after engaging in the first set of activities (Q1) showed that the number of participants formulating Level-3 arguments regarding the causes of climate change doubled (25%). These participants supported their arguments by providing more than one reason. One of the participants, who claimed that human activities cause climate change, argued that in case the increase in the globe's temperature was due to changes in the Sun, climate change would have occurred a very long time ago. Moreover, he claimed that researching space is more laborious. Therefore, there is not enough evidence that supports model B. He also said that evidence shows that carbon dioxide gas emitted through human activities is contributing to the increase of the Earth's temperature, as shown in the excerpt below:

> *Model A since from like 2 million years ago till now, why didn't our Sun produce more and more heat back then it was releasing more heat back then why didn't it explode? If the cause of the increase in temperature were from the Sun, it would have happened a million years ago. It is our fault because we are surrounding the earth with pollution, so of course, CO2 will increase, and the temperature will increase which leads to melting in the poles and makes the ozone layer weaker. Heat is from carbon dioxide gas emission. I don't know if there is enough evidence to believe that it is from the solar system because it is harder to do research there. So the evidence from people who believe that is because of human activities is more research and evidence there isn't much evidence about the solar system because researching space is more difficult, but evidence for human activities are available (P5, Q1)*

Another participant, who supported Model B, argued that changes in the solar system cause climate change. She supported her justification claiming that some planets are heating up and emitting certain substances. These substances are reaching Earth and causing an increase in the temperature of the earth. She also explained that the speed of planets that are moving around the Sun is slowing down. Consequently, these planets are spending more time near the Sun and heating the Earth. Furthermore, she thought that the Earth is getting closer to the Sun, as seen in the excerpt below:

> *For example, Venus, if it has acids, it might come to earth, and it might affect polluting, and climate change is happening. Maybe other planets are making the earth warmer. They are not moving close to each other and to the Sun. Each planet has its own time of moving [around the Sun], but they are moving slower and spending more time closer to the sun. Additionally, the heat and the acids of all the planets that are hot are reaching the earth and increasing the level of heat (P8, Q1)*

Context-2: Water fluoridation. Analysis of responses of the open-ended questions after the second set of activities (Q2), in the context of water fluoridation, demonstrated that one participant did not answer the question. The number of participants, who developed Level-1 arguments about the positive and negative effects of water fluoridation, dropped sharply to zero (Table 15). Moreover, the percentage of Level 2 decreased from 43.7 % to 25%. These participants provided one reason to justify their arguments. A participant argued that she defended the Model that is supported by stronger evidence, as shown in the excerpt below:

> *I support model A because water fluoridation is not a bad issue since more proof and evidence was provided (P15, Q2)*

One of the participants mentioned the ethical considerations related to water fluoridation to support her argument. She opposed the idea of water fluoridation because she thought that it is unethical to force people to intake medication before asking for their approval, as shown in the excerpt below:

Model B because it is not ethical to give people medication without asking (P20, Q2)

After engaging in the second set of activities (Q2), the percentage of Level 3 increased from 25% to 68.7 % (Table 14). More participants were able to support their arguments by providing more than one justification regarding adjusting the amount of fluoride in public water. These participants explained that they support a specific Model based on the availability of current and robust evidence. The participants, who opposed water fluoridation, mentioned the economic problems faced by dentists and the health problems faced by people in general, as shown in the excerpt below:

Model B because it has more evidence since the evidence is more exact and well researched, and it has more current information, and it sounds more correct. It is more exact and detailed. It has more evidence, and the evidence of it is more current. For example, the evidence that supports model A is since the 70s, and the evidence supporting model B is like 2009, like lately not really old. Water fluoridation is a solution in the end then it will damage the economically. It will damage the dentists. Dentists use fluorine, and now people will take them (P22, Q2)

Another participant who supported water fluoridation argued that water fluoridation has more disadvantages than advantages. He mentioned that excess of fluorine might cause health problems such as nerve problems and a decrease in IQ. He argued that people might visit dentists to cure their teeth cavities instead of risking to intake extra fluorine, as illustrated in the excerpt below:

> *Fluorine shouldn't be put in the water because it has many negative effects on the human body like lower IQ in the brain and damages the nerves… we can go to the dentist and not put fluoride in the water and can get anti-cavity teeth. There are many negative effects that explain model B, but model A had only one effect focused on like okay, we may go to the dentist and not put fluoride in the water, and we will not get negative effects which are fluorine has. The negative effects of fluorine are a lot since it causes many disadvantages to the human body (P14, Q2)*

Context-3: Electromagnetic wave pollution. As shown in Table 15, after engaging in the third set of the activities (Q3) in the contexts of electromagnetic wave pollution, one participant (6.2 %) was classified as Level-1 because she did not give any justification to support her argument whether electromagnetic waves cause cancer or do not harm people. as shown in the excerpt below:

> *I support Model A (P20, Q3)*

The percentage of the participants classified as Level-2 did not vary after engaging in the third set of activities (Q3). Twenty-five percent of the participants provided one reason to support their arguments about the effects of electromagnetic waves on people's health. One participant mentioned that electromagnetic waves are harmful. Other participants focused on the validity of information and the availability of evidence, as shown in the excerpts below:

> *I support Model A because I think that electromagnetic waves are harmful and make cancer (P21, Q3)*

I think that Model B is my point of view because the data provided is right about model B (P18, Q3)

I would support Model B although there is not enough evidence because it has more valid data (P12, Q3)

Similarly, the percentage of participants classified as Level-3 stayed constant at 68.7 % (Table15). These participants were able to provide more than one reason to support their arguments and explain how electromagnetic waves affect people. One of the participants, who opposed electromagnetic wave production, argued that electromagnetic waves coming from routers and technological devices cause cancer and other diseases. He thought that people who use technology have 30% more chance to get cancer. Besides, he claimed that cows produce less milk and children have lower IQ when exposed to electromagnetic waves, as shown in the excerpt below:

I support Model A because if the routers or technology cause cancer, then we would have had an increase in cancer diseases. Facts such as people with technology in their houses have a 30% chance of getting cancer than people who live without technology because of the experiment they made on cows and children because cows are producing less milk on the electromagnetic waves and the children on the electromagnetic waves, the IQ was lower. It says that things are causing cancer, so it is connected to electromagnetic waves anyway. It is not completely 100%. (P9, Q3)

Another participant, who was not against the production of electromagnetic waves, considered that electromagnetic waves do not cause harm based on the evidence provided in the MEL-diagrams. He claimed that electromagnetic waves coming from devices are so weak that not to harm the body. He added that the number of people diagnosed with cancer has not increased in the past 30 years, as shown in the excerpt below:

> *I support Model B since evidence 8 in the MEL diagram proves that no increase in cancer is happening. Also, because in evidence 1, they are showing that electromagnetic waves are weak to knock out electrons and directly damage the body. Evidence 6 is telling that based on 25000 articles, no health consequences are shown. So we conclude that this doesn't harm our body in our daily lives, almost every person has a phone and uses it and is in front of the electromagnetic wave. And in evidence 8 they said looking at the last 20-30 years, we don't see an increase in cancer. So electromagnetic wave doesn't harm our body (P9, Q3)*

Context-4: Animal testing. After engaging in the fourth set of activities (Q4), in the context of animal testing, none of the participants formulated Level 1 arguments to explain whether animal testing is acceptable or not acceptable (Table 15). Six participants (37.5 %) formulated Level 2 arguments by providing one reason to support their justification regarding the acceptance of animal testing. Several participants supported their arguments and expressed their rejection of animal testing by mentioning that animal testing is harmful to the animals, as shown in the excerpt below:

> *My opinion is that I am not with animal testing because animals should not be harmed (P21, Q4)*

Others supported a certain Model based on the availability of data or evidence, as shown in the excerpt below:

I support Model B because there is more data supporting it (P15, Q4)

Another participant supported animal testing and considered it acceptable because she considered that it is an effective method for protecting humans from diseases, as shown in the excerpt below:

I support Model A because I think that animal testing is a perfect way to protect human (P10, Q4)

In the context of animal testing, the number of participants formulating Level 3 arguments decreased from 68.7% to 56.2%. These participants provided more than one reason to support their justification regarding the acceptance of animal testing. Most of the participants did not consider animal testing acceptable. Therefore, they focused on ethical issues related to animal testing and suggested alternative ways of testing medications. For example, one of the participants was against animal testing even though he considered that the alternative view is supported by evidence that is more robust. He argued that harming animals is unacceptable because animals are living species, and people do not have the right to kill them. He also thought that testing on sample cells or volunteers might replace animal testing and stop harming the animals. He also suggested using special machines as an alternative for animal testing, as shown in the excerpt below:

Since we don't have the right to test on animals. I found it like there is more evidence supporting model A. But I myself support model B since I find it unacceptable. It is not our right to harm animals because they are living species like us. We can get samples of volunteers or us is that of harming animals because it is not right to harm the animals. We should not harm animals, and it is not our right. Instead, we should build machines to test on *them, or we can get samples of what we like to test and not like the whole body (P14, Q4)*

Another participant, who was against animal testing, also added that animal testing might not provide valid results considering the biological differences between humans and animals as shown in the excerpt below:

I support Model B because of evidence 6 because experimenting on cell cultures instead of whole animals, using computers or human volunteers are possible ways for replacing animal testing, not all experiments work on all animals it might work on animals, and it might not work on humans. In the future, experimenting on cell cultures instead of whole animals, using computer models, and studying human volunteers all possible ways to replace animal testing because other than [evidence] 6, also I found that here and evidence 4 not all, not work on all animals it might work on animals, and it might not work on humans (P2, Q4)

Post-test: Genetically modified food. As shown in Table 15, analysis of responses in the post-test indicated that none of the participants formulated Level 1 arguments regarding the production and consumption of GMF after engaging in four sets of activities, and 18.7% formulated Level 2 arguments (Table 15). One of these participants considered that the reasons for opposing the production of GMFs are minimal in the absence of experiments that ensure the safety of Golden Rice, as shown in the excerpt below:

No, because the first scientist should try this type of rice and see if it's good or not then see if they could sell it. This rice has benefits if we eat it but first do experiments before we eat (P21, post)

Another participant opposed the production of golden rice and focused only on the side effects of golden rice, as shown in the excerpt below:

> *Golden rice should not be produced and sold to people because even if it helps to prevent blindness by improving vitamin A, it may affect other things. It would have a negative impact on the other thing on the other side it is good, but on the other side it may be bad (P15, post)*

Analysis of responses to the open-ended questions in the post-test indicated that the number of participants formulating Level 3 arguments increased remarkably to thirteen (81.0%) (Table 15). These participants were able to support their justifications by more than one reason to support their position regarding the production and consumption of golden rice. They considered the advantages and disadvantages of golden rice production and consumption. They discussed the ethical considerations of golden rice production and questioned the validity of the information regarding the production of golden rice, considering that enough experiments are not performed regarding this issue. Moreover, they mentioned the financial benefits of golden rice production. For example, one of these participants, who supported the production of golden rice, argued that it prevents blindness and cures vitamin A deficiency. He also claimed that the consumption of golden rice is a cheap way to prevent blindness instead of performing surgeries. This participant was aware of the dangers caused by planting golden rice on other types of plants. However, he considered that the advantages of golden rice are more than its disadvantages. He showed interest in reading more about the adverse effects of GMFs, as shown in the excerpt below:

Yes, since golden rice has all the advantages that rice has golden rice prevents blindness by giving us extra vitamins A and the rate of children getting blind may fleas if they eat the Golden Rice because it prevents blindness for the poor people it is a very cheap way to prevent blindness instead of doing many surgeries they can keep eating golden rice. Although I am with the idea of not producing it because it may change the way the plants grow and I don't want this to happen, but I am bored to producing it. It has the same idea of the rice, but it is more advanced it contains more vitamin A. I will try to search for articles whether it affects the plants or not (P14, post)

Another participant repeated similar reasons as above to support the production of GMFs. However, he elaborated his justifications by claiming that the safety of GMF production might be validated as more research studies are conducted. He also suggested ways of reducing the negative effects of golden rice on other plants, as illustrated in the excerpt below:

Yes, golden rice should be produced because it helps people with blindness and with vitamin A deficiency as it has been tested several times on animals. It can help keep their children not to get blind. It gives them [children] a lot of vitamins when they are still young. It is helpful for countries that don't have much food. Maybe they don't have enough and need to get the vitamins. Maybe, they don't have vitamin A or vitamin B, and that is not healthy for them because they get diseases faster. It is better to do this thing; it is better to help people. If there is a negative effect and there are positive effects like helping blindness, maybe they can put them in special places, or they don't grow plants they just put it special fertilizers so that the plants grow fast or maybe just put it in a small place to test on it. If it causes harm more than the *stuff that they already found out, then they should have some more. If it doesn't affect the plants they can put it with the other (P9, post)*

Another participant, who opposed the production of GMFs, argued that golden rice is unhealthy for people. She claimed that it is unethical to force people to eat GMF, considering that biomedical tests are not performed to check its safety, as illustrated in the following excerpt:

Genetically modified food is not healthy for people, and they can't force people to eat modified food. Even though now no biomechanical analysis of holding wife has shown later with advanced technology the negative effect of modified school will be shown (P11, post)

Analysis of changes in counterarguments for the whole class. The following section provides the analysis of changes in the participants' ability to formulate counterarguments as a whole class. It provides examples of responses from each level of argumentation in the pretest, posttest, and each of the contexts of social-controversial issues.

Pre-test: Genetically modified food. As shown in Table 14, analysis of the responses in the pre-test indicated that, in the context of genetically modified food (GMF), none of the sixteen participants formulated Level 3 counterarguments regarding the production and consumption of GMF. Whereas, two participants (12.5 %) generated counterarguments that were classified at Level 1 because they gave no justification to support their position regarding the production of GMF. One participant did not formulate counterarguments. Two of the participants, instead of explaining what opponents might think, provided more reasons for convincing the opponents with her arguments. For example, a participant who supported the production of GMF, instead of providing counterarguments, claimed that she might argue with her opponents and provide more reasons to convince them as seen in the excerpt below:

I would support professor Ponso with my decision by arguing with him about and telling him that it can help many people worldwide just with rice (P4, pre)

On the other hand, analysis of responses indicated that the vast majority of the participants (81.2 %) formulated Level 2 counterarguments in the pre-test. These participants provided only one reason that challenges their argument. They thought that the opponents might either focused on the negative effects of golden rice and suggest to replace golden rice with other sources of vitamins of as shown in the excerpts below:

I think professor Ponso would make me realize the negative effects instead of the positive effects (P9, pre)

He will say that you may take this vitamin from another medicine (P16, pre)

He will convince me by saying that there might be something wrong with the DNA and it could be very harmful (P20, pre)

Context-1: Climate Change. After engaging in the first set of activities (Q1) in the context of climate change, analysis of responses indicated that four participants did not answer the question that aimed to assess their ability to formulate counterarguments regarding the causes of climate change. Moreover, analysis of the responses also showed that 18.7 % of the participants formulated Level-1 counterarguments that challenge their justification (Table 15) while two of these participants did not provide any justification. They just repeated the claim that was already provided in the models as seen in the excerpts below:

I think they will say that it is model B since the sun is giving lots of energy to the earth, so it is not, so it is creating climate change (P22, Q1)

They might tell me that it's because of the solar system and that is the point of climate change (P10, Q1)

One participant provided one reason that might be claimed by the opponents to challenge her argument about the causes of climate change, as shown in the excerpt below:

He might show me negative things and be convinced by the people who are against him (P8, pre)

The number of participants formulating Level-2 counterarguments regarding the causes of climate change decreased from 81.2 % to 50% after engaging in the first set of activities (Q1) (Table 15). These participants mostly considered that the opponents might provide evidence that supports the alternative argument and thus challenges their argument A participant who believed that human activities cause climate change thought that her opponents would show the measurements of satellites that show an increase in the energy received by the sun, as shown in the excerpts below:

They would tell me information about their topic and why they chose it. Maybe the experiments they have done and more data like a satellite from this year to this year showed increase in this much (P2, pre)

They will tell me facts and evidence about the opposing model (model B) facts and evidence which is happening nowadays like about the sun releasing more heat by searching about it about his point of you or his hypothesis and try to gather facts and try to convince me (P14, pre)

Other participants, who thought that human activities cause climate change, provided one reason given by the opponents that challenge their argument, as shown in the excerpt below:

They could tell me that natural things happen and that the sun is giving more heat (P20, Q1)

They will tell me that everything can change in the solar system normally. You never know what will change in our solar system (P19, Q1)

After engaging in the first set of activities (Q1), in the context of climate change, only one participant (6.2%) was able to generate Level 3 counterargument by providing more than one reason that challenges his argument. As he argued that human activities cause climate change, this participant mentioned his opponents would tell that the sun is getting closer to the earth, and the satellites are establishing that more energy is coming from the Sun, as shown in the excerpt below:

He will be telling it is happening now that the sun is getting closer to the earth, and satellites are measuring more energy coming to the earth by the humans may be going out to space and closer to the sun (P9, Q1)

Context-2: Water fluoridation. Analysis of responses of the open-ended questions after the second set of activities (Q2), in the context of water fluoridation, demonstrated that three participants did not answer the question. The number of participants who developed Level-1 counterarguments dropped to one (Table 15). A participant provided evidence to support her argument instead of generating counterarguments that describe the viewpoints of her opponents. Even though she claimed that she is against water fluoridation because of ethical considerations, P20 provided more evidence to support her view, as shown in the excerpt below:

I would tell them that it causes diseases it is not ethical it also decreases IQ (P20, Q2)

Moreover, the percentage of Level 2 participants remained constant at 50% (Table 15). These participants provided one counterargument that challenges their arguments regarding their acceptance of fluoridation of public water. Some of the participants mentioned the advantages or disadvantages of water fluoridation, and others mentioned the ethical issues related to it, as shown in the excerpts below:

Maybe he will tell me that maybe people don't want to drink water like we are letting people take fluoride, and maybe some people don't want to take fluoride (P16, Q2)

They would tell me that everything may have bad effects on a person (P15, Q2)

They would say it is ok to drink extra fluorine It is good for the teeth (P5, Q2)

After engaging in the second set of activities (Q2), the percentage of Level 3 participants increased from 6.2 % to 43.7 % (Table 15). More participants were able to generate counterarguments for more than one reason. One of the participants who supported water fluorination formulated counterarguments mentioning that opponents might provide evidence to show that fluoride causes a decrease in IQ, nerve problems, and hypothyroidism, as shown in the excerpt below:

Maybe they might show me a video of people trying experiments on people who have trying extra fluorine water it shows the symptoms of these health problems like decrease in IQ levels, neurological dysfunction, and hypothyroidism (P9, Q2)

Another participant, who was against water fluoridation, formulated three counterarguments. She stated that opponents might challenge her by arguing that fluorine is healthy and prevents tooth decay. She thought that they might claim that fluorination is a cheap and more accessible way of preventing tooth decay, as shown in the excerpt below:

> *They might say that it [fluoridated water] is healthy for you and try to persuade me that it is cheaper than going to the dentist. They might tell me like that it prevents tooth cavity because it is easier than going the dentists. You can drink it in your water, and it can help your teeth (P22, Q2)*

Context-3: Electromagnetic wave pollution. Analysis of responses of the open-ended questions after the third set of activities (Q3), in the context of electromagnetic wave pollution, demonstrated that three participants did not answer the question. The number of participants who developed Level-1 counterarguments stayed constant at one (Table 15). This participant, who argued that electromagnetic waves cause cancer and suggested that more experiments be performed to prove that her argument is right instead of generating counterarguments, as shown in the excerpts below:

> *My explanation would be that support model A and do an experiment. Put your phone in your room there will be an electromagnetic wave, and they are harmful (P21, Q3)*

The percentage of the participants classified as Level-2 dropped to 25% after engaging in the third set of activities (Q3) (Table 15). These participants picked out evidence from the MEL-diagram that contradicts their argument and provided them as counterarguments, as shown in the excerpts below:

They would support their position by [evidence 6] telling me current studies do not confirm the existence of any health consequence regarding electromagnetic waves (P15, Q3)

I think he will talk about evidence number 4 [that electromagnetic waves cause diseases and infertility] (P18, Q3)

Finally, after engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, half of the participants (50%) were able to general Level 3 counterarguments regarding the effects of electromagnetic waves on people's health. Several participants, who thought that electromagnetic waves are not harmful, claimed that their opponents would argue about prioritizing people's health over the financial benefits resulting from manufacturing devices that emit electromagnetic waves. They also claimed that their opponents might challenge them by discussing health problems and other disadvantages caused by electromagnetic waves, as shown in the excerpt below:

They will tell me that economics is not important to the health of the people. He will tell that electromagnetic waves cause cancer, which is big harm on the body, and if he supports model A, he is a person who just cares about his health a lot, and he does not care about economics, everyone who supported model A, they are. (P16, Q3)

They will explain to me about its disadvantages, like electromagnetic waves, cause diseases like cancer and infertility. They will give evidence that supports model A. like the many symptoms of electromagnetic waves cause diseases like evidence 4 after the MEL diagram… like telling me what I said the opposite of what I said like I said I support my model B by evidence 1 they will *show me evidence 3 or 4 which are the counter of what evidence 1 shows (P14, Q3)*

Context-4: Animal testing. After engaging in the fourth set of activities (Q4), in the context of animal testing, two participants did not answer the question. Analysis of responses demonstrated that the number of participants who developed Level-1 counterarguments regarding their acceptance of animal testing stayed constant at one (Table 15). This participant stated that her opponents would support her argument with evidence, as shown in the excerpt below:

I will talk with him about my point of view and will support it with data and evidence (P18, Q4)

Four participants (25 %) formulated Level 2 counterarguments by providing one reason to challenge their justification regarding their acceptance of animal testing (Table 15). Participants, who were against animal testing claimed that their opponents would prioritize humans' health over harming animals or consider animal testing the most efficient way of testing medicines without harming humans, as shown in the excerpts below:

They will tell me that at last humans are important (P15, Q4)

They would say that there is no choice except testing on animals not to harm humans (P12, Q4)

Another participant, who was also against animal testing, thought that his opponents would argue that animal testing helps people to diagnose diseases as the same diseases affecting the animals might affect humans, as shown in the excerpt below:

Diseases that damage the human brain are in the same as the mice's brain (P19, Q4)

In the context of animal testing, the number of participants formulating Level 3 counterarguments remained constant at 50% (Table 15). These participants provided more than one reason that challenge their justification.

A participant who was against animal testing thought that his opponents would challenge his argument by suggesting that animal testing is more useful because samples of a cell may die immediately and not allow performing tests effectively. Moreover, he mentioned that his opponents might find testing animals easier and faster for finding medication to fatal diseases, as shown in the excerpt below:

They [opponents] might say that it [animal testing] is more useful to use the animals. Like if they use it is better because we have something maybe cells die like if we use cells, they might die immediately and if we use the cure and use it on the animals that have many cells, it might affect it in another way like some might die, but it might heal in the same way. So it might be different for the animals, and it is better because it is easier and faster. the cure for the disease that is fatal it can be finished as fast as possible (P9, Q4)

Another participant, who was also against animal testing, thought that her opponents would consider harming animals as an acceptable way of testing medications and protecting humans as shown in the excerpt below:

He will tell me that it is ok it is acceptable to harm a few animals, and he will say that it is for our [humans] sake, and nothing is dangerous about it. That is, it is ok to test animals, and nothing dangerous will happen (P2, Q4)

Finally, a participant, who supported animal testing, thought that her opponents would argue that animals are threatened and hurt when testing on them. She thought that her opponents would refuse killing animals because people need animals to feed on, as shown in the excerpt below:

They will say that animals will be endangered and we need animals to eat (P10, Q4)

Post-test: Genetically modified food. As shown in Table 15, the analysis of responses of the post-test indicated that none of the participants formulated Level 1 counterarguments regarding the production and consumption of GMF after engaging in four sets of activities. The number of participants who formulated Level 2 counterarguments increased from 25% to 56.2% (Table 15). Most of these participants gave one counterargument. Several participants, who were against the production of GMFs and golden rice, thought that their opponents might argue that golden rice might prevent blindness and cure vitamin A deficiency as shown in the excerpts below:

This rice is modified which produce or give vitamin A and helps you and other things (P21, post)

He can say that eating genetically modified rice with the two extra games can help blindness (P20, post)

Processor Punto will tell me that as it has negative effects, it also has positive effects like it provide the body vitamin A while digestion (P16, post)

Participants who supported the production of golden rice thought that their opponents might argue that a healthy balanced diet is enough for curing Vitamin A deficiency. Moreover, they felt that the opponents might also say that animal testing might affect the other plants negatively, as shown in the excerpt below:

Golden rice can have many negative effects because it can change the genes in the plant and what is it made a new disease (P19, post)

Professor Ponso will say that having a healthy and more balanced diet is better than eating golden rice (P18, post)

Analysis of responses to the open-ended questions in the post-test indicated that seven participants (43.7%) formulated Level 3 counterarguments (Table 15). These participants were able to provide more than one reason that might challenge their argument regarding the production and consumption of GMF. Participants who were for the production of golden rice thought that their opponents would argue that biomedical tests are not available to verify the safety of golden rice. Also, they would identify the side effects of golden rice and its disadvantages to the surrounding plants. These participants also mentioned some solutions that might be suggested by their opponents, as illustrated in the excerpts below:

He will say that we don't really know the biochemical analysis of the golden rice to see how adding two genes may have changed the plant as a whole. A healthy balanced diet would be a better solution than the golden rice to deal with vitamin A deficiency. First your she would say that when we plant the modified rice with the normal plant, it makes the regular rice stronger since we are planting them together. They will take vitamin A, or they will share vitamin A and even if the. Society takes the normal rice there is no doubt of the side effects because you are getting it with extra vitamin A and it may affect you (P5, post)

Another participant, who supported the production of golden rice, mentioned similar ideas. However, he also thought that his opponents might consider the necessity of conducting experiments and ensuring the safety of golden rice, as seen in the excerpt below:

I think that professor Ponso will say that it does help early child blindness and vitamin A deficiency. It might not be 100% right and could kill us. He will probably tell that it hasn't been tested out of people. Maybe it can affect plants and how they act. Maybe it can change something in the flower decomposers or something. That still hasn't been tested on humans that much, so they are still working probably. They need to do more research on it or try to do experiments on it or on plants. Or maybe just tested in countries were really needed who really need it so it still can help.

Finally, a participant, who opposed the production of golden rice, thought that the proponents might argue that golden rice is healthy because it prevents blindness and provides vitamins, as shown in the excerpts below:

He would really just focus on the positive effects, and they would think that it is the only cure for blindness. They will only stay [focused] on the positive effects because they want to realy think that the negative effects are more important than the positive effects. They can tell that golden rice prevent blindness and provides vitamins, so it is healthy, and if we need to take like normal vitamins scientists still need to research about it to see more about it (P8, post)

Table 15

Distribution and Percentages of Students' Argumentation Skills for the Four Social Controversial Issues

Context	Pre-test		Climate Change		Water Fluoridation	
(N=16)	Argument	Counterargument	Argument	Counterargument	Argument	Counterargument
Level 1	2 (12.5 %)	2 (12.5 %)	5 (31.2 %)	3 (18.7 %)	0 (0 %)	0 (0 %)
Level 2	12 (75 %)	13 (81.2 %)	7 (43.7 %)	8 (50%)	4 (25 %)	8 (50.7%)
Level 3	2 (12.5%)	0 (0%)	3 (18.5 %)	1 (6.2 %)	11 (68.7 %)	7 (43.7 %)

Context	Electromagnetic Wave Pollution		Animal Testing		Post-test	
(N=16)	Argument	Counterargument	Argument	Counterargument	Argument	Counterargument
Level 1	1 (6.2 %%)	1 (6.2 %)	0 (0 %)	1 (6.2 %)	0 (0 %)	0 (0 %)
Level 2	4 (25 %)	4 (25 %)	6 (37.5%)	4 (25%)	3 (18.7 %)	9 (56.2 %)
Level 3	11 (68.7%)	8 (50%)	9 (56.2%)	8 (50%)	13 (81.2%)	7 (43.7%)

Analysis of changes in arguments by participants. The following section presents the analysis of the changes in the argumentation skills of the participants throughout this research study, starting from the pre-test to the four sets of activities (Q1, Q2, Q3, and Q4) and the post-test. Additionally, this analysis compares each participant's skills in formulating arguments and counterarguments throughout the intervention to study the development of their argumentation skills in the contexts of climate change, water fluoridation, electromagnetic wave pollution, and animal testing. Additionally, three participants were randomly selected to analyze their responses in detail and prepare summary profiles for each.

As shown in Table 16, analysis of the responses of the pre-test indicated that, out of sixteen participants, two participants (12.5%) formulated Level 1 arguments, 75% formulated level 2 arguments and 12.5% formulated level 3 arguments in the context of genetically modified foods (GMFs). However, the number of participants generating Level 1 arguments decreased to 0% in the post-test (Table16), while 18.7% formulated level 2 arguments, and the majority (81.2%) formulated level 3 arguments. It is worth noting that after engaging in information credibility evaluation activities and reflective discussions, participants were able to provide more reasons to support their justifications. Below please find the detailed analysis of the responses of three randomly selected participants to the question that aimed to assess their ability to formulate arguments.

Participant 5. Before engaging in the four sets of activities, analysis of the responses of the pre-test indicated that P5 was already able to formulate Level 3 arguments in the context of genetically modified food. P5 argued that he is against the production and consumption of golden rice. He supported his argument by claiming that medical tests have not been performed to ensure the safety of golden rice on people's health. He thought that this might result in errors if the effect of GMFs on people's health. Moreover, he considered that the modification of regular rice is not necessary because it is already beneficial for humans, as shown in the excerpt below:

> *They should not produce and sell golden rice to anyone before testing everything so that it will be secure, and everyone takes it and makes sure there are no side effects. Also, [it should not be sold] because there is no need for modifying a thing if it [rice] already has its benefits it is all about human's health (P5, pre)*

After engaging in the first set of activities (Q1) in the context of climate change, P5 also formulated Level 3 arguments to claim that human activities cause climate change. He argued that in case the increase in the globe's temperature was due to changes in the sun, climate change would have occurred a very long time ago. Moreover, he claimed that researching space is more laborious. Therefore, there is not enough evidence supporting an alternative claim which claims that changes in the solar system cause climate change. He also said that evidence shows that carbon dioxide gas emitted through human activities is contributing to the increase of the Earth's temperature, as shown in the excerpt below:

> *Model A since from like 2 million years ago till now, why didn't our Sun produce more and more heat back then. If it was releasing more heat back then why didn't it explode? If the cause of the increase in temperature were from the Sun, it [climate change] would have happened a million years ago. It is our fault because we are surrounding the earth with pollution, so of course, CO_2 will increase, and the temperature will increase, which leads to melting in the poles and makes the ozone layer weaker. Heat is from carbon dioxide*

gas emission. I don't know if there is enough evidence to believe that it is from the solar system because it is harder to do research there. So the evidence from people who believe that is because of human activities is more research and evidence there isn't much evidence about the solar system because researching space is more difficult, but evidence for human activities are available (P5, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P5 kept on formulating Level 3 arguments regarding the effects of public water fluoridation on humans. P5 provided more than one reason to describe his opposition to water fluoridation. He claimed that ever person might react differently to fluorine. He thought that many people might benefit from fluorine; however, others might be harmed from it. Likewise, he argued that people should have the choice of drinking fluorinated water or no. He considered forcing people to intake fluorine against their will unethical act, as shown in the excerpt below:

Model B since we are not all the same people who need more fluorine because of health problems. Some people don't have health problems. So, the only solution is making water bottles which have extra fluorine and water bottles which don't have a lot of fluorine. As I said before, depending on the body type maybe people don't want to drink water like we are letting people take fluoride, and maybe some people don't want to take fluoride (P5, Q2)

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P5 kept formulating Level 3 arguments to clarify that he considers that electromagnetic waves cause cancer. He claimed that more evidence is provided in favor of Model A, which contended that electromagnetic waves cause cancer than in favor of Model B. He specified that evidence shows that cows produce less milk when exposed to electromagnetic waves. He concluded that electromagnetic waves are harmful to people, as shown in the excerpt below:

> *Model A because there is more robust evidence supporting model A. For example, in evidence 5, when they remove the current underground cows produced ten times more milk, which concludes that it [electromagnetive waves] is harmful. This is a piece of strong evidence that strongly supports model A (P5, Q3).*

In the context of animal testing, after the last set of activities (Q4), P5 generated another Level 3 argument to show his opposition to animal testing. He claimed that it is unethical to harm animals by performing tests on them. Besides, he argued that some tests might be successful in animals but not on humans. For this reason, he considered that animal testing might be replaced by more accurate technology, as shown in the excerpt below:

> *Model B, because evidence strongly supported it, and in my opinion, if you think logically, it is not really ethical. Evidence 6 greatly supports this, which can possibly develop include technology to replace animal testing. That is great evidence to support the model. For example, evidence 4 shows that we are harming the animals, and then we are curing them, but it is not curing us. So why to harm animals if we get other things [differences in medical results]? It's all about ethical [issues]. As you think about it is really ethical is the main problem for animal testing (P5, Q4).*

In the post-test, P5 provided several reasons to justify his argument regarding the production and consumption of GMFs. He argued that GMFs should be produced and consumed because he thought that it is an efficient way of providing medication to poor people. Moreover, he clarified that it is possible to give people the choice of consuming golden rice or regular rice. In this way, he thought that no one would be forced to consume chemicals. In addition, he claimed that adverse effects of golden rice might be easily solved when golden rice is planted isolated from normal rice to avoid gene exchange between modified and normal rice, as illustrated in the excerpt below:

> *I am with the thought of selling golden rice but only to the people who are sick and need golden rice so that there will be two options to buy; the first one, without modified rice, the second one with modified rice. Since there are two options to buy rice, both modified and not modified rice will not be planted together. There would be a section for modified rice and a section for non-modified rice. We can give the poor and the sick people the medication while the normal person can take the regular ones so that we don't force the society to take the medication and not knowing the side effects, so it is better to have two options. Also, the regular rice has its property to grow healthy while the golden rice has its own property to grow healthy and normal and replant them together, they will make a change, maybe which is not convenient to the others and genetics. Changing the genetics of the plant with vitamin A may cause other problems to the plant and about to us (P5, post)*

Participant 8. Analysis of the pretest showed that P8 was already able to formulate Level 3 arguments. Before engaging in the activities, P8 argued that biomedical tests are not performed to ensure the safety of GMF. She claimed that a healthy diet and normal vitamin intake is enough because the excess of vitamin A might also be harmful as seen in the excerpt below:

Because it is not approved by scientists and might be dangerous because they might do something wrong with the genes that we do not realize. It's better to be patient and take normal vitamins and have a healthy diet. It is still not created, and no one really specified how it really works and how much to take as amount. Extra vitamin A also may not be healthy, and maybe they don't know how much they should take (P8, pre)

After engaging in the first set of activities (Q1), P8 generated Level 1 arguments because she provided invalid justifications to support her views regarding the causes of climate change. She argued that some planets are heating up and emitting certain substances. These substances are reaching Earth and causing an increase in the temperature of the earth. She also explained that the speed of planets that are moving around the sun is slowing down. Accordingly, these planets are spending more time near the sun and heating the Earth. Furthermore, she thought that the Earth is getting closer to the Sun, as seen in the excerpt below:

For example, Venus, if it has acids, it might come to earth, and it might affect pollution. And climate change is happening. Maybe other planets are making the earth warmer. They are not moving close to each other and the Sun. Each planet has its own time of moving [around the Sun], but they are moving slower and spending more time closer to the sun. Additionally, the heat and the acids of all the planets that are hot are reaching the earth and increasing the level of heat (P8, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P8 also provided more than one reason to support her justification and develop a Level 3 argument. She argued that she was against fluoridating public water because she thought that water fluoridation might cause financial problems to the dentists. She explained that when fluorinated water is available to the public, people might intake more than the needed amount and develop diseases. She claimed that extra fluorine causes a decrease in IQ. For this reason, she considered that other solutions for tooth decay are available. She mentioned that people are already consuming fluorine from different sources, such as toothpaste. Therefore, she thought that there is no need to take more fluorine, as shown in the excerpt below:

> *Yes, because if it [fluoridated water] is sold anywhere, dentists will lose a lot of money. The dentists are curing the tooth cavity they are advising their patients to do. They remove the tooth cavity. They give their patients medicine or toothpaste or any other thing, or they even might give them the water, but it is better not to sell it in public places, and only the dentist will sell them. The dentist knows how much it should be and what is the case, and he will give it to the people they will specify the amount to take. It is better than taking them more fluoride by mistake. They will give them more information other than the information that they already know. Moreover, the positive effect is only preventing tooth cavity, but in model B, we have different types of problems that are happening in the body, but they are not really thinking about that it will lower IQ in children… here they are saying that there is no need to take it because we already have advanced toothpaste. So it is a better first place not to take it because we have other solutions and other ways that are better for society and for the people (P8, Q2)*

Engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution allowed P8 to provide more than one reason to argue that electromagnetic waves harm the human body. She claimed that this position is supported by more robust and convincing current evidence than the alternative position. She considered that enough evidence is not provided to suggest that electromagnetic waves are harmless. She also mentioned the harmful effects of electromagnetic waves to strengthen her argument further. She claimed that electromagnetic waves are dangerous and fatal. She also said that cows produce less milk when they are exposed to electromagnetic waves, as shown in the excerpt below:

> *I support model A because the negative effects [of electromagnetic waves] are really dangerous, and you're not willing to take a risk to die. I think that model A is more supported [by evidence] than model B because all evidence supporting model A are common supportive ideas that aren't really convincing. Even though model B says that it does not harm our body, we should pay attention to that it might cause cancer. Maybe they said that it does not, but we should pay attention that it might because they don't have a specific reason that it does not. They did not test it before. For example, here the evidence 2 told us in 1989, it does not make a very good, it does not really support because it is from a long time ago. So, I still support model A because it might give us disease. Based on evidence no 5, if you are really close to electromagnetic waves, the cow does not produce a lot of milk; it actually makes us discover new sicknesses new diseases we have never heard anything like that the cow does. We have never heard about something like this before. So, scientists can discover new diseases so that they can be recovered. They can make it more productive like all people can use technology so they can discover new things and solve it (P8, Q3)*

After engaging in the fourth set of activities (Q4) in the context of animal testing, P8 kept on formulating Level 3 arguments to describe her opposition to animal testing. She argued that harming animals by making tests on them is not moral. She also claimed that some tests might be successful in animals but not on humans. Hence, she thought that animal testing is not entirely secure. Furthermore, she considered that animals should not be used for testing medications because she thought that they are part of nature and provide food and other benefits to humans, as seen in the excerpt below:

> *Model B because harming animals is really dangerous and affects humans. Since they are saying, let's say evidence 2, which says that the level of suffering and the number of animals involved are both so high that the benefits of humanity don't provide moral justification. It is not supporting model A. It is more supporting model B because they are telling us what is happening to humans when animal testing is happening. So it shows the negative effects of model A. As I said from before, animals help humans to live and plants and all of nature help us to live… they give us benefits (P8, Q4)*

Finally, P8 developed a Level 3 argument to show her opposition to the production and consumption of GMFs in the post-test. She gave several reasons to justify her arguments. First, she claimed that biomedical tests are not available to prove the safety of golden rice. Therefore, she thought that golden rice might have side effects that are not yet discovered. To support her argument further, she mentioned a number of the negative effects of golden rice consumption. For example, she claimed that golden rice is affecting other plants planted around it. Moreover, she argued that when golden rice is available to people, they might not be able to control the dosage of the golden rice intake and develop serious health problems. Finally, she suggested that a healthy balanced diet is enough to cure Vitamin A deficiency, as shown in the excerpt below:

No. Golden rice should not be produced since scientists still know if it could add a new thing to our DNAs, which could cause physical changes or undiscovered diseases. That we still don't know if it is the only cure, and we yet don't know if it adds or switches DNA because it is not approved by scientists and might be dangerous because they might do something wrong with the genes and we not realize. It's better to be patient and take normal vitamins and have a healthy diet. It's still created, and no one really specified how it really works and how many to take as an amount. It isn't scientifically confirmed and tested. They might just predict that because they have changes genes and LOOKS like it gives vitamin A … also because people might take more than they need to make their vision maybe even worse, or it would prevent blindness. So what can they do as they can take normal vitamins every day or go to a doctor so that they can see what they can do regarding blindness? You can eat other things that can be healthy like fruits and vegetables, so it isn't really a big thing to think about (P8, post)

Participant 22. Analysis of the responses to the pre-test showed that P22 provided only one reason to justify her opposition to the production and consumption of golden rice. For this reason, her argument was classified as a Level 2 argument. She only claimed that the intake of chemicals might be unhealthy and harmful to humans, as shown in the excerpt below:

I don't think it should be sold because in the end the chemical is not healthy and might be dangerous for the body (P22, pre)

After engaging in the first set of activities (Q1) in the context of climate change, P22 argued that human activities cause climate change. She supported her argument by providing one reason. She thought that climate change is caused by human activities only because more robust and current evidence is available to model A. She highlighted the importance of checking current evidence, as seen in the excerpt below:

> *I support Model A since it sounds true, and evidence is strongly supporting model A. Also, it makes more sense since nowadays, lots of human activities release gases, and because evidence strongly supports the model like the other one was not very strong evidence. Also, it is more current because that is what is happening now, so that is more current. Everybody knows that human activities are releasing lots of gases because that is what is happening now, so that is more current (P22, Q1)*

Engaging in the second set of activates (Q2) in the context of water fluoridation helped P22 to improve the quality of her justifications and to formulate Level 3 arguments. P22 opposed the idea of adding fluoride to public water because she thought that Model B is supported with robust and well-researched evidence. She also mentioned that more current evidence supports model B than model A. Additionally. She argued that fluoride that is added to drinking water causes health problems and claimed that people working in the dentistry field might face financial problems because people might visit dentists less, as shown in the excerpt below:

> *I think model B is correct since the evidence is more exact and well-researched. Model B, because it has more current information, and it sounds more correct because it has more evidence, and the evidence of it is more current. For example, the evidence that supports model A is since the 70s, and the evidence supporting model B is like 2009, like lately not really old. For*

example, they say the different health problems [of fluoridated water]. It is more exact and detailed. If water fluoridation is a solution in the end, then it will damage the economy. Those who work in water companies and don't want to lose their jobs like it will damage the money of the water companies.(P22, Q2)

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P22 also formulated Level 3 arguments to clarify that electromagnetic waves are harmful to humans. She mentioned more than one negative effect of the electromagnetic waves to support her justification. First, she thought that stronger, more convincing/exact, and current evidence supports model A rather than model B. She claimed that children exposed to electromagnetic waves are more likely to be diagnosed with cancer and stated that cows produce less milk when they are exposed to electromagnetic waves, as shown in the excerpt below:

I support Model A since it has more evidence strongly supporting it, and the evidence is more accurate and current. Also, it is more commonly supported around the world. In evidence 3, they were comparing children that were exposed to electromagnetic waves and children that were not, and they realized that the people next to electromagnetic waves were more exposed to having cancer, and they also noticed that cows that are exposed to electromagnetic waves produce less milk. Because the evidence is more accurate is more current and more detailed and also is more commonly supported, more people supported model A (P22, Q3)

Analysis of the responses of the fourth set of activities (Q4) in the context of animal testing showed that P22 kept on formulating Level 3 arguments to oppose animal testing and prevent its application. She provided more than two reasons to support her justification. First, she thought that more evidence supports her position that the alternative one. Second, she considered animal testing is an immoral act. Additionally, she claimed that some tests might be successful when done on animals but not on humans. Therefore, she suggested that animal testing might be replaced by testing samples of cells instead of animals. She thought that this method might be more accurate than technology, as shown in the excerpt below:

> *Model B, since it is more accurate and has more evidence and is more commonly supported, it has more evidence supporting it. Most people support Model B because it has more evidence, and the evidence about it shows that it [animal testing] is not good to do it, and it is immoral. Evidence 3 says that it might not work because animals have different bodies than humans; that is, the cells of the animals are not identical do human cells. So, it also might not work. Evidence 5 and Evidence 6 are telling us about ideas to stop animal testing and try different things. I also have an idea if they want to more natural animal testing, they can take like samples of the human body cells and test on them. That will be more accurate, and it will not harm anyone, so it's better. (P22, Q4)*

Finally, responses to the posttest demonstrated that P22 was able to develop Level 3 arguments by providing more than one reason to justify her opposition to golden rice production and consumption. She claimed that GMF is not healthy because it is modified and inorganic food. For this reason, she thought that GMFs might not provide the same benefits to everyone but instead might endanger them. Therefore, she suggested that a healthy balanced diet is enough to prevent Vitamin A deficiency, as illustrated in the following excerpt:

I don't think it should be sold since golden rice is genetically modified and genetically modified food are not healthy. Also, people don't know the dangers of this. Golden rice also might not work for all people. We don't know the dangers since the machines we are using are not accurate enough. GMF is not healthy, no matter what. Even if they try to make it healthy, it still, in the end, is made of chemicals, and it is added genes and stuff. It is not natural or organic food, so we shouldn't be eating it. Also, if we have a balanced diet, it is just as good because it is actually healthier because you are getting more stuff than this golden rice. It is just giving vitamin A. if you eat a balanced diet, you are going to get a lot of different vitamins. The tools that they are testing with are not strong enough. It can't detect the danger. Maybe they have to make different machines. Also maybe it didn't show. It might show later in different experiments and studies (P22, post)

Summary of changes in formulating arguments. Analysis of changes in argumentation skills for the whole class and by participants answered the second part of the first research question. The analysis indicated that, after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues, more participants developed Level 3 arguments. In the pre-test, only two participants were able to formulate Level 3 arguments. Throughout the research study, most of the participants gradually developed the ability to formulate Level 3 arguments. The analysis of the post-test showed a remarkable increase in the number of the participants formulating Level 3 arguments from two participants (12.5%) to thirteen participants (81.2 %) (Table 16). However, even though most participants (68.7%) formulated Level 3 arguments after engaging in the second set of activities (Q2), the number of these participants slightly decreased when participants were asked to argue in the context of animal testing (Table 16).

Analysis of changes in counterarguments by participants. As shown in Table 16, analysis of the responses of the pre-test indicated that, out of sixteen participants, two participants (12.5%) formulated Level 1 counterarguments, 81.2 % formulated level 2 counterarguments and 0% formulated level 3 counterarguments in the context of genetically modified foods (GMFs). However, the number of participants generating Level 1 counterarguments decreased to 0% in the post-test (Table 16), while 56.2% formulated level 2 counterarguments, and 43.7% formulated level 3 arguments. It is worth noting that after engaging in information credibility evaluation activities and reflective discussions, participants were able to provide more reasons that challenge their justifications. Below please find the detailed analysis of the responses of three randomly selected participants to the question that aimed to assess their ability to formulate counterarguments.

Participant 5. Before engaging in the four sets of activities, analysis of the responses in the pre-test indicated that P5 was able to formulate Level 2 counterarguments in the context of GMFs as P5 argued that he is against the production and consumption of golden rice, he thought that his opponents might claim that the modifications of genes are secure and normal, as shown in the excerpt below:

> *I think Professor Ponso will tell me that it is ok to modify a gene. It is just making it better, and everything will be normal and secure (P5, pre)*

After engaging in the first set of activities (Q1) in the context of climate change, P5 also formulated a Level 2 counterargument to explain how his opponents will challenge his position as he argued that human activities are the cause of climate change, he claimed that his opponents might state that some research on the solar system shows that the sun is causing an increase in temperature, as shown in the excerpt below:

> *They would say scientists have done the research and discovered that the sun recently has been giving us more heat. They will say they say that something is happening in the solar system, but we still don't we still need to know some research to conclude that (P5, Q1)*

After engaging in the second set of activities (Q2) in the context of water fluoridation, P5 also formulated a Level 2 counterargument regarding his views on the effects of public water fluoridation on humans. P5 opposed water fluoridation and claimed that opponents might challenge him by stating that consuming extra fluorine is acceptable as long as it is beneficial to the teeth, as shown in the excerpt below:

> *They would say it is ok to drink extra fluorine. It is good for the teeth depending on the body type (P5, Q2)*

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P5 was able to formulate Level 3 arguments to clarify that he considers that electromagnetic waves cause cancer. He provided more than one reason to describe reasons that challenge his position. He argued that electromagnetic waves are harmful to humans, and he thought that his opponents might challenge his argument by claiming that thousands of articles show that electromagnetic waves do not harm the body. Moreover, he thought that people supporting the alternative view might argue that in the past ten years, the number of people diagnosed with cancer has not increased, as shown in the excerpt below:

They will maybe talk about Evidence 6 and Evidence 8 since nothing really happened nowadays and the past. No one develops cancer; articles show people do not have cancer because of electromagnetic waves (P5, Q3)

In the context of animal testing, after the last set of activities (Q4), P5 generated another Level 3 counterargument to show the reasons given by his opponents. As P5 opposed animal testing, he claimed that his opponents might argue that animal testing benefits humanity by providing medications. Likewise, he thought that his opponents might consider medicines tested on animals to be more trustworthy and claim that animal testing reduces the risk of people taking the wrong medication, as shown in the excerpt below:

They would say it is important to do animal testing so that we don't doubt if humans are getting the right medication. The ideas are like it will benefit and help humanity more. What I mean is model A encourages animal testing on animals so that we get the medication and not the doubtful medication, but still, it is not ethical (P5, Q4).

In the post-test, P5 formulated a Level 3 counter-argument by proving several reasons that may challenge his argument regarding the production and consumption of GMFs. He argued that GMFs should be produced and consumed because he thought that they are efficient in providing medication to poor people. However, he also thought that his opponents might challenge his argument by mentioning the disadvantages of golden rice. He thought that his opponents might argue that biomedical tests are not available to prove the safety of golden rice. For this reason, golden rice has side effects. He also thought that his opponents might consider that a healthy balanced diet is enough to cure Vitamin A deficiency. Moreover, P5 added another negative challenge to his argument might be that golden rice may affect other plants planted around it, as shown in the excerpt below:

They will say that we don't really know the biochemical analysis of the golden rice to see how adding two genes may have changed the plant as a whole. A healthy balanced diet would be a better solution than the golden rice to deal with vitamin A deficiency. First your she would say that when we plant the modified rice with the normal plant, it makes the regular rice stronger since we are planting them together they will take vitamin A, or they will share vitamin A, and even if the society takes the normal rice there is no doubt of the side effects because you are getting it with extra vitamin A and it may affect you (P5, post)

Participant 8. Analysis of the pretest showed that P8 was able to formulate Level 2 counterarguments before engaging in the activities. P8, who was against the production and consumption of GMFs. She claimed that her opponents might argue that GMFs cure diseases, as seen in the excerpt below:

He might say that people will be cured easier (P8, pre)

After engaging in the first set of activities (Q1), P8 also generated Level 2 counterarguments in the context of climate change. P8 stated that her opponents might clarify that there are different views regarding the causes of climate change and ask her to take a position. As P8 thought that changes in the solar system cause climate change, she claimed that her opponents might mention evidence of adverse effects of human activities to convince her that climate change is caused by human activities, as seen in the excerpt below:

He will show some negative effects to convince me. They would say that scientists have two opinions and I need to choose one. They might give me proof and might convince me more, but people might be against their opinion I might, he will [try] to convince me, but I will not be convinced with him. He might show me negative things and be convinced with the people who are against him. (P8, Q1)

After engaging in the second set of activities (Q2) in the context of water fluoridation, P8 provided more than one reason that challenge her justification and developed a Level 3 counterargument. Since P8 was against fluoridating public water, she claimed that her opponents might argue that water fluoridation prevents tooth decay and improves people's living conditions. She thought that her opponents might support their position by stating that research studies have shown that fluoride prevents tooth decay. Moreover, she claimed that her opponents might strengthen their arguments by claiming that dentists might find cures for the diseases caused by excess fluorine, as shown in the excerpt below:

They might say that dentists can find a solution for not having or causing diseases. They will say that it will make the world a better place maybe and find researches about how it is good that it will help the tooth cavity, but maybe they will find researches from 1975 or 2009, so that is basically what are saying here. What they were saying in the past, so they are going to find the researches that were conducted before (P8, Q2)

Engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution allowed P8 to provide more than one reason that challenge her opposition to electromagnetic wave emission. P8 argued that electromagnetic waves are harmful to the human body. For this reason, she thought that her challengers might say that, based on 25000 articles, electromagnetic waves are not harmful, and over the last 30 years, people did not encounter an increase in cancer as shown in the excerpt below:

> *They are telling that if you are exposed to a low level of electromagnetic waves, it doesn't do anything to the health, and it is ok, and this is based on 25000 articles. They will convince me of the evidence, of course. Let's say Evidence 2; they would say that science times reported that. For example, Evidence 8, they will say that over the last 20-30 years, people do not encounter cancer. They might see that they might have focused on one specific person and tried what would happen if, for a year, he will stay with the technology and use technology and electromagnetic wave, (P8, Q3)*

After engaging in the fourth set of activities (Q4) in the context of animal testing, P8 kept on formulating Level 3 counterarguments to describe the opposing views of her argument regarding animal testing. Since she argued that causing suffering to the animals by making tests on them is not moral, she thought that her opponents might say that animal testing is safer when done on animals instead of on humans. She claimed that her opponents might support their views by submitting that evidence supporting their position is more current, as seen in the excerpt below:

> *They might say that animals are like humans. He will say that it is better to test on animals. They will keep on focusing on this evidence that they have found for model A, and they will not think of the things that I am saying. They will not be convinced in my way. They are 100% sure that their opinion is current (P8, Q4)*

Finally, in the post-test, P8 developed a Level 3 counterargument to show how her opponents might challenge her opposition to the production and consumption of GMFs. She gave several reasons that challenge her argument. For example, she thought that her opponents might mention the positive effects of golden rice and argue that it is healthy because it provides Vitamins and prevents blindness. She thought that her opponents would prioritize the positive effects of GMFs over the negative effects, as shown in the excerpt below:

> *He would really just focus on the positive effects, and they would think that it is the only cure for blindness. They will only stay on the positive effects because they want to really think that the negative effects are more important than the positive effects. They can tell that golden rice prevent blindness and provides vitamins, so it is healthy, and if we need to take like normal vitamins scientists still need to research about it to see more about it (P8, post)*

Participant 22. Analysis of the responses to the pre-test showed that P22 provided only one reason that challenges her opposition to the production and consumption of golden rice. For this reason, her counterargument was classified as a Level 2 counterargument. She only claimed that her opponents might think that golden rice is healthy because it is prepared with precision, as shown in the excerpt below:

> *I think it is healthy since we added genes precisely and we are sure it will help (P22, pre)*

After engaging in the first set of activities (Q1) in the context of climate change, P22 argued that human activities cause climate change. Moreover, she provided a Level 2 counterargument by mentioning one reason that challenges her position regarding the causes of climate change. She thought that her opponents might argue that the sun is releasing more energy that is causing climate change on Earth, as seen in the excerpt below:

> *I think they will say that it is model B since the sun is giving lots of energy to the earth, so it is creating climate change (P22, Q1)*

Engaging in the second set of activates (Q2) in the context of water fluoridation helped P22 to improve the quality of her responses and to formulate Level 3 counterarguments. She provided more than one reason that might challenge her opposition to water fluoridation. As P22 opposed the idea of adding fluoride to public water, she claimed that her opponents might consider that fluorine is healthy and prevents tooth decay. Moreover, she thought that her opponents might argue that fluorination is a cheaper and more natural way of preventing tooth decay, as shown in the excerpt below:

> *They might say that it's healthy for you, and try to persuade me that it is cheaper than going to the dentist. They might tell me like that it prevents tooth cavity because it is easier than going the dentists you can drink it in your water, and it can help your teeth (P22, Q2)*

After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P22 also formulated Level 3 counterarguments to clarify what her opponents might argue regarding the effects of electromagnetic waves. As she mentioned more than one negative impact of electromagnetic waves to support her justification, she also thought that people supporting the alternative view might claim that over the past 30 years the number of people diagnosed with cancer did not increase and argue that electromagnetic waves are too weak to cause harm to people as shown in the excerpt below:

I think they would say that over the past 30 years, studies do not show that these waves are harmful, and either way, the waves are harmless because they are too weak to knock out electrons and damage the body. They would say that lots of articles over the past 30 years don't realize that anything affects the body from electromagnetic waves (P22, Q3)

Analysis of the responses of the fourth set of activities (Q4) in the context of animal testing showed that P22 kept on formulating Level 3 counterarguments to provide evidence that opposes her view regarding animal testing. Earlier, she argued that animal testing is an immoral act that does not ensure the accuracy of medicines. Therefore, she thought that the opponents of her view might consider that animals are less important than humans. She added that they might also argue that animal testing saves people from dying by contributing to the discovery of medicines. She thought that they see animal testing as the right way of testing the medicines before using them for humans, as shown in the excerpt below:

They do animal testing to test the medicines and drugs on the animals before they use it on humans because they think that the animals do not matter as much as humans. So losing an animal is not as important as losing a human. so that's why they do it on animals (P22, Q4)

Finally, responses to the posttest demonstrated that P22 was able to develop Level 3 counterarguments by providing more than one reason that challenges her opposition to golden rice production and consumption. Since she claimed that golden rice is not healthy, she considered that her opponents might argue that there is no evidence regarding the adverse effects of golden rice. Moreover, she thought that they might find golden rice an efficient way of curing a common health problem like blindness, as illustrated in the following excerpt:

> *I think he will say "no studies have indicated any dangers related to genetically modified foods" and "this affected 500,000 Children worldwide each year". Maybe he will tell me that they did tests on GMF, and nothing showed that it causes dangers. (P22, post)*

Table 16

Frequency Distribution and Percentages of Students' Argumentation Skills

Argumentation component	Argument		Counterargument	
(N=16)	Pre	Post	Pre	Post
Level 1	2 (12.5 %)	0 (0 %)	2 (12.5 %)	0 (0%)
Level 2	12 (75 %)	3 (18.7 %)	13 (81.2 %)	9 (56.2 %)
Level 3	2 (12.5%)	13 (81.2 %)	0 (0 %)	7 (43.7%)

Summary of changes in formulating counterarguments. Analysis of changes in argumentation skills for the whole class and by participants indicated that, after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues, more participants developed Level 3 counterarguments. In the pre-test, none of the participants was able to formulate Level 3 counterarguments. Throughout the research study, most of the participants gradually developed the ability to formulate Level 3 counterarguments. The analysis of the post-test showed an increase in the number of the participants formulating Level 3 counterarguments from 0% to 43.7% (Table 16).

Second Research Question: How are alternative information evaluation argumentation skills related after engaging in reflective discussions from the perspective of FRA

Part 3: Relationship between Alternative Information Evaluation and Argumentation Skills.

To study how alternative information evaluation and argumentation skills are related after engaging in reflective discussions from the perspective of FRA, the argumentation levels of each set of activities were correlated with the scores of each MEL-diagram through which the participants evaluated alternative information. To answer the second research question, the relationship between participants' abilities to evaluate alternative information and to formulate arguments were analyzed and described.

The researcher assessed how participants had linked evidence boxes of the MEL-diagrams to the Models, and graded participants' responses based on the key of the MEL-diagram suggested by Lombardi et al. (2016) (Figure 3). Each arrow drawn to link an evidence box to a model was equivalent to one grade. Therefore, the overall score of the Mel-diagram was based on the number of arrows that had to be drawn. For this reason, the MEL-diagram on the first set of activities was over 8; those of the second and the third sets of activities were over 16 and the MEL-diagram of the fourth set of activities (Q4) was over 12. The researcher calculated all the grades over ten and compared the results of the four MEL-diagrams that were solved during each set of activities (Q1, Q2, Q3, and Q4).

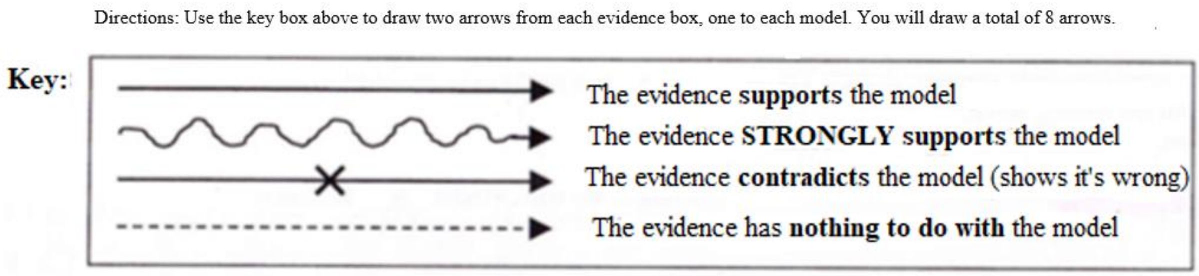

Figure 4: MEL Diagram Key

Table 17 presents the scores of the alternative information evaluations (over 10) and the argumentation levels that were analyzed and categorized in the previous section. Analysis of the results indicated that the scores of alternative information evaluation and argumentation levels are not positively correlated.

In several cases, participants who scored low on alternative information evaluation formulated Level 3 arguments, while those who scored high grades on information evaluation, formulated Level 1 arguments. For example, P5 scored 5/10 on the information evaluation because out of eight arrows, and he linked four evidence boxes to models using the right arrows, as shown in Figure 5.`

However, P5 developed Level 3 argument in the first set of activities and was able to formulate a Level 3 argument about the causes of climate change. He provided more than one reason to support his view. P5 claimed that human activities cause climate change and argued that in case the increase in the globe's temperature was due to changes in the sun, climate change would have occurred a very long time ago. Moreover, he claimed that researching space is more laborious. Therefore, there is not enough evidence supporting an alternative claim that claims that changes in the solar

Table 17

Scores of Alternative Information Evaluation (MEL-Diagrams) and Argumentation Component after each Set of Activity

Participants N=16	A1	Q1 /10	A2	Q2 /10	A3	Q3 /10	A4	Q4 /10
2	3	7.50	3	6.25	3	8.12	3	5.80
4	2	3.75	3	6.25	3	7.50	3	5.80
5	3	5.00	3	5.00	3	6.25	3	4.10
8	3	10.0	3	5.62	3	8.12	3	7.50
9	3	3.75	3	3.75	3	4.37	3	5.0
10	2	2.50	2	4.37	3	5.62	2	5.80
11	1	7.50	3	7.50	3	7.50	3	4.10
12	1	6.25	-	8.12	2	6.80	2	3.30
14	2	2.50	3	6.80	3	7.50	3	5.80
15	2	2.50	2	4.37	2	5.0	2	3.30
16	2	6.25	2	2.50	3	6.25	-	-
18	1	2.50	3	3.75	2	5.62	2	3.30
19	2	7.50	3	7.50	3	7.50	3	6.60
20	1	6.25	2	4.37	1	6.25	2	5.80
21	1	2.50	3	6.25	2	5.0	2	2.50
22	2	8.25	3	5.00	3	6.80	3	7.50
Average		4.60		5.40		6.50		5.0

system cause climate change. He also said that evidence shows that carbon dioxide gas emitted through human activities is contributing to the increase of the Earth's temperature, as shown in the excerpt below:

> *Model A since from like 2 million years ago till now, why didn't our Sun produce more and more heat back then it was releasing more heat back then why didn't it explode? If the cause of the increase in temperature were from the Sun, it would have happened a million years ago. It is our fault because we are surrounding the earth with pollution, so of course, CO2 will increase, and the temperature will increase...*

which leads to melting in the poles and makes the ozone layer weaker. Heat is from carbon dioxide gas emission. I don't know if there is enough evidence to believe that it is from the solar system because it is harder to do research there, so evidence from people who believe that is because of human activities is more research and evidence. There isn't much evidence about the solar system because researching space is more difficult, but evidence for human activities are available (P5, Q1)

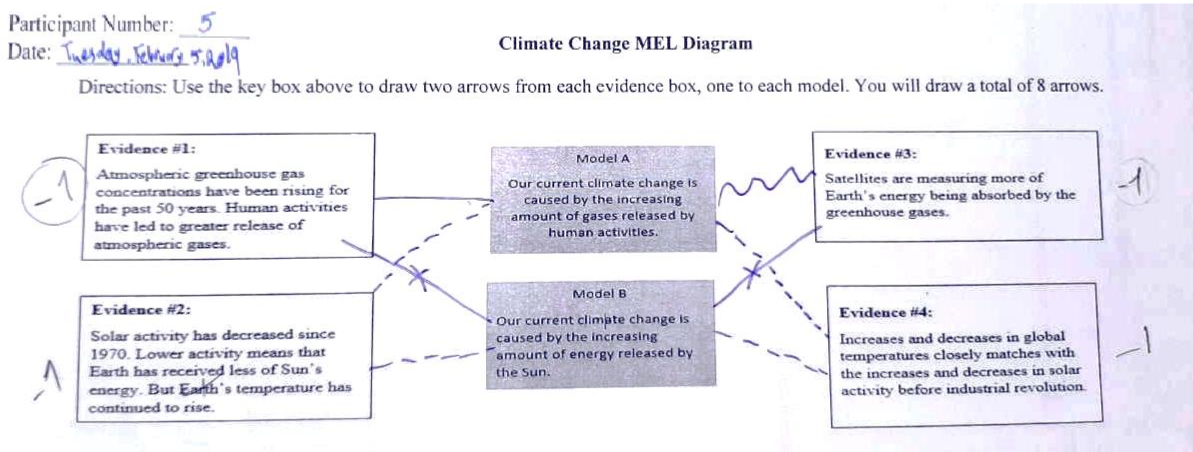

Figure 5: The climate change MEL-diagram of P5 after engaging in the first set of activities (Q1)

In other cases, participants who formulated a Level 1 argument scored higher in the alternative information evaluation compared to those who were able to develop Level 3 arguments. For example, P10 scored the highest grade (7.50/10) on the information evaluation after engaging in the first set of activities (see Figure 6); however, she scored Level 1 argument in the context of climate change. P10 did not give any reason to support her position regarding the causes of climate change. Although she argued that human activities cause climate change, she repeated the claim without providing any justification to defend her position, as seen in the excerpt below:

Model A. These days a lot of greenhouse gases has been produced (P10, Q1)

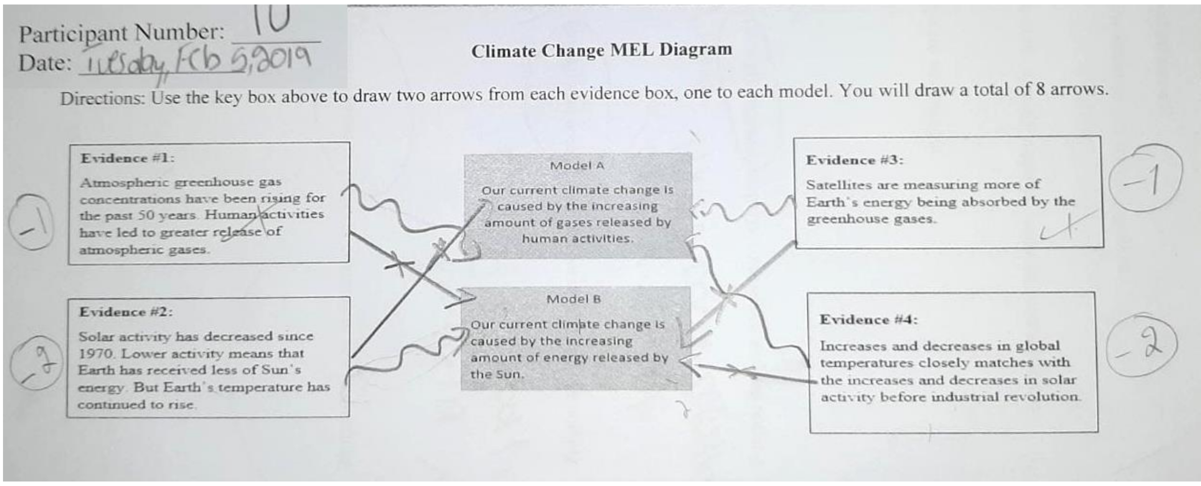

Figure 6: The climate change MEL-diagram of P10 after engaging in the first set of activities (Q1)

Another example that indicated that alternative information evaluation and formulation of arguments are not positively correlated are the responses of P11 after engaging in the fourth set of activities. P11 was able to formulate a Level 3 argument after participating in the fourth set of activities in the context of animal testing; however, she scored 4.10/10 on alternative information evaluation task (see Figure 7).

Moreover, in some cases, participants scoring the same in alternative information evaluation formulated arguments of different levels. For example, both P10 and P14 scored 5.80/10 on the information evaluation task after engaging in the fourth set of the activities (Q4) (see Figures 8 and 9, respectively); however, they formulated Level 2 and Level 3 arguments, respectively. P10 gave one reason to support her argument. She argued that animal testing is acceptable because it protects humans from diseases, as shown in the excerpt below:

> *I support Model A because I think that animal testing is a perfect way to protect human (P10, Q4)*

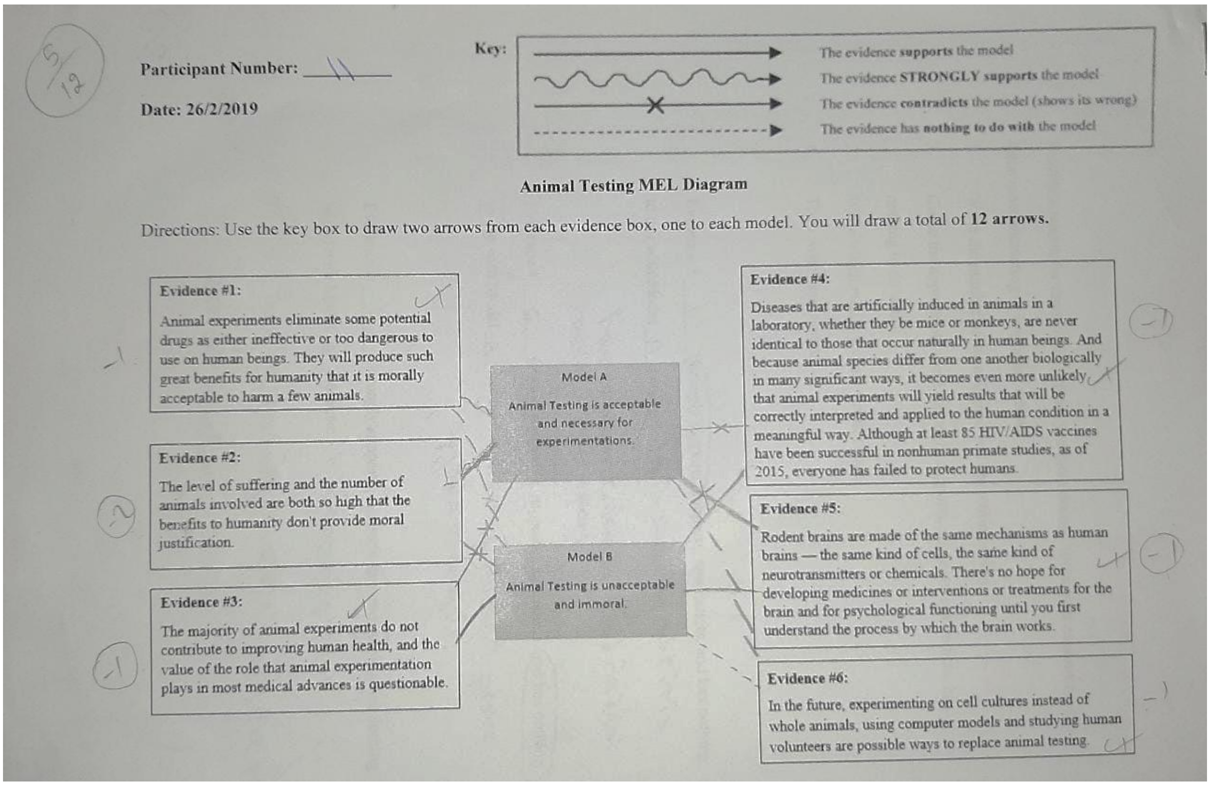

Figure 7: The animal testing MEL-diagram of P11 after engaging in the fourth set of activities (Q4)

While P14 provided several reasons to argue that animal testing is unacceptable ack. He claimed that animals are living species, and humans do not have the right to kill them. He also mentioned that using special machines to test medicines, testing on sample cells or volunteers might replace animal testing and stop harming the animals as shown in the excerpt below:

> *I support Model B since we don't have the right to test on animals. I found it like there is more evidence supporting model A but Me Myself supports model B since I find it unacceptable. It is not our right to harm animals because they are living species like us. We can get samples of volunteers or us is that of harming animals because it is not right to harm the animals. We should not harm animals, and it is not our right*

instead, we should build machines to test on them, or we can get samples of what we like to experiment and not like the whole body (P14, Q4)

To verify the results of the descriptive and qualitative analysis of the correlation between the alternative information evaluation skills and the ability to formulate arguments, the researcher analyzed this relationship using SPSS software as well. The numeric correlation verified the descriptive qualitative correlation analysis. Table 18 shows the results of the Pearson correlation analyzed with SPSS software. The SPSS analysis indicated that, after the first set of activities (Q1), the argumentation levels are negatively correlated with the scores of the information evaluation assessed by the first MEL-diagram (-0.127). On the other hand, the results showed that there was a low correlation between the argumentation levels and the MEL-diagram scores of the rest of the sets of activities (Q2, Q3, and Q4).

Summary of the relationship between alternative information evaluation and argumentation skills. Analysis of the relationship between information evaluation and argumentation skills allowed the researcher to answer the second research question. The analysis indicated that there is a very low correlation between the scores of the alternative information evaluation and the level of the arguments formulated by the participants. In several cases, participants who scored low on alternative information evaluation formulated Level 3 arguments, while those who scored high grades on information evaluation, formulated Level 1 arguments. In other cases, participants scoring the same in alternative information evaluation formulated arguments of different levels. Nevertheless, in general, the average scores of the alternative information evaluation and the ability of the participants in formulating

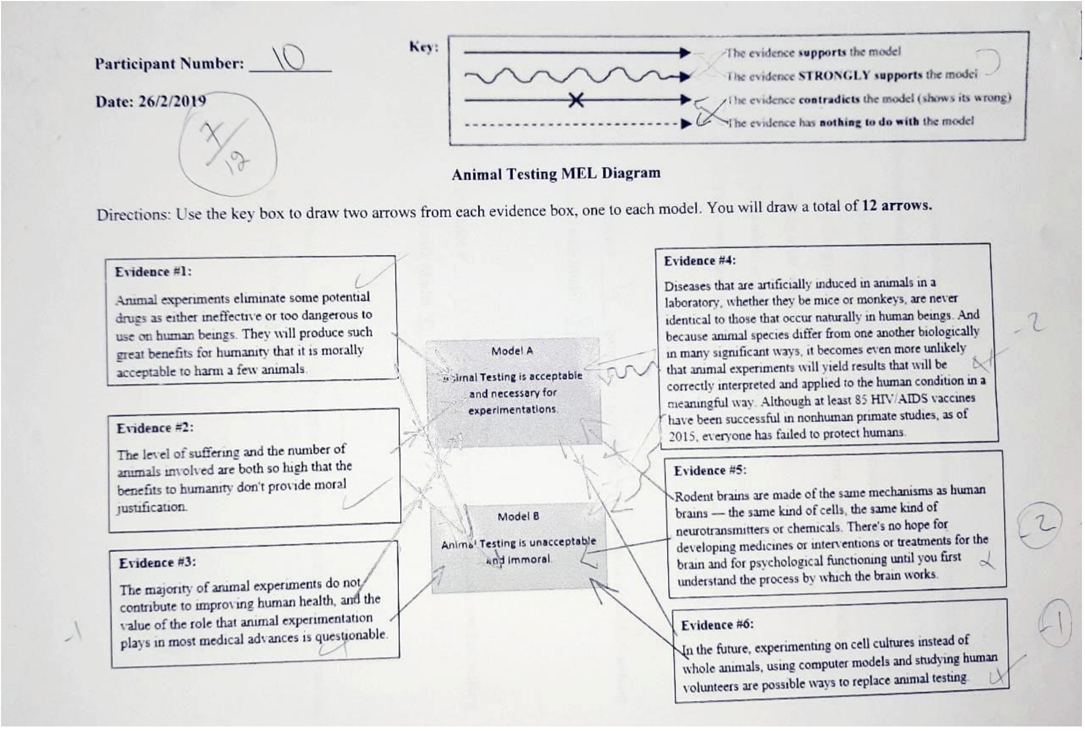

Figure 8: The animal testing MEL-diagram of P10 after engaging in the fourth set of activities (Q4)

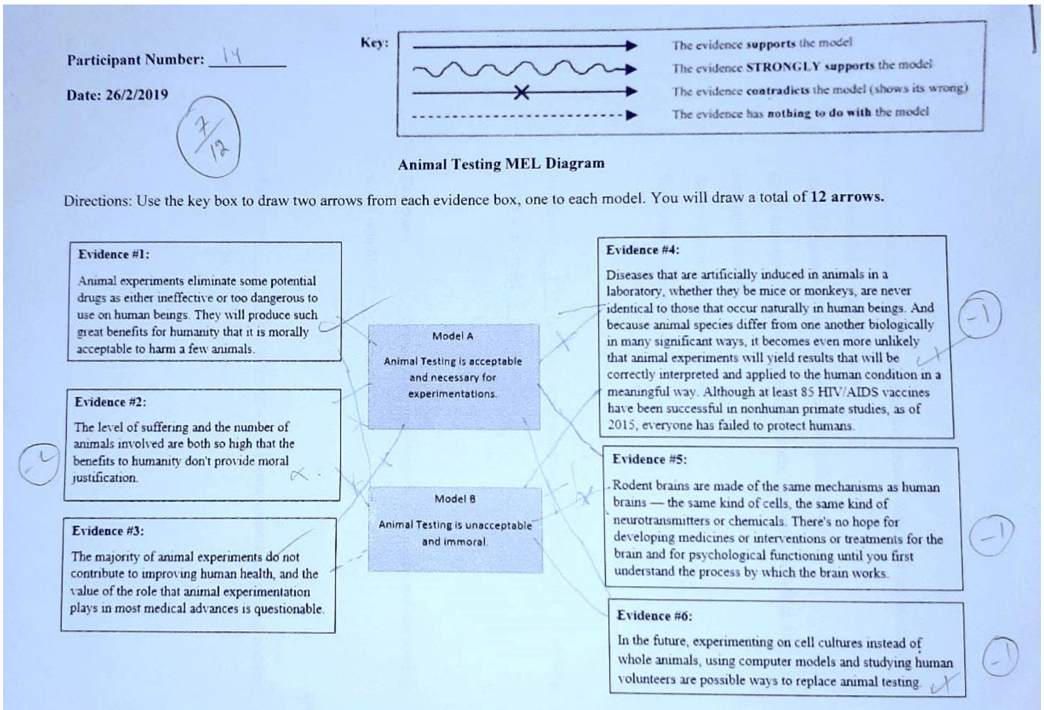

Figure 9: The Animal Testing MEL-diagram of P14 after engaging in the fourth set of activities (Q4)

Table 18

Pearson Correlation among Arguments and MEL-diagram Scores after each Set of Activity

	MEL-1	MEL-2	MEL-3	MEL-4
Q1 Argument	-0.127			
Q2 Argument		0.588		
Q3 Argument			0.386	
Q4 Argument				0.251

Correlation is significant at the $\alpha = 0.05$ level (2-tailed)

Level 3 arguments improved throughout the research study. Even though the scores of information evaluation increased from 4.50 to 6.50 as the participants engaged in the first three sets of activities (Q1, Q2, and Q3) in the contexts of climate change, water fluoridation, and electromagnetic wave pollution respectively, the alternative information evaluation scores dropped in the context animal testing to 5.00.

Part 4: Variation in NOS Views: Returning to a former or less developed state of NOS views.

Throughout the analysis process of NOS views, the researcher found several cases of participants returning to a former or less developed state, which we identified as “Variation” in NOS views. Analysis of changes in NOS views by participants demonstrated several variation cases. Although, in general, NOS views of the participants developed throughout the research study, the development was not consistent for many participants. Out of a hundred and sixty responses (responses of sixteen participants to ten different NOS themes), data analysis detected fifty-four cases of Variation throughout the pre-test, Q1, Q2, Q3, Q4, and the post-test. Mostly, the NOS views varied from informed to intermediary views. For example, P9 showed informed views of the relationship between science and politics in the third set of activities and the post-test. After engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, P9 thought that people who reject exposure to electromagnetic waves might protest against the government, and post opinions on their social media accounts about their concerns. Besides, he claimed that some governments invest money on costly machinery for producing electronic devices. He thought that governments improve economically as they produce, export, and sell electronic devices. He also said that both governments and scientists work on producing electronic devices that do not cause harm to people, as shown in the excerpt below:

> *It is connected immediately the scientists and government acknowledge and trying to make devices that do not have electromagnetic waves, or they are very low, and if that happens, they will keep on sending it to people who are afraid of getting cancer, and they still want Wi-Fi. it will give them a lot of money that is the economics will be high for electronics, and it will help the government a lot but the machines to make electronics will cost a lot (P9, Q3)*

However, after engaging in the fourth set of activities (Q4) in the context of animal testing, his views changed from informed to intermediary views. In the context of animal testing, his views suggested that the relationship of science and politics is limited to the opposition of people to decisions taken by scientists and governments regarding the application of animal testing and their demand for replacing animal testing with alternative methods of testing medications as shown in the excerpt below:

People of society have different opinions regarding animal testing. This may cause people to oppose scientists and the government to find alternative ways of testing medications other than animal testing (P9, Q4)

On the other hand, in the post-test, P9 showed informed views of the relationship between science and politics again and thought that scientists give recommendations to governments based on their research studies. Moreover, he considered that applying these recommendations might cost the government a large amount of money and rise economic problems in the country, as shown in the excerpt below:

If electromagnetic waves or like the phone that have Wi-Fi and everything causes brain damage or cancer, the scientist tells the government about it economics will go down for electronics then nobody will buy electronics because they are bad for them and it will cause them danger, and maybe it causes other stuff. They have to make new electronics that don't cause that, but obviously, it will take a while, and it will cost a lot of electronics will go down, and maybe the government needs more money, but they can't. So cause this whole motion maybe they can tell the government to fix the factories that emit gas or CO2 that are bad... and they will tell them that this is not good for you and you should fix it where everything dies (P9, post)

Only in one case, the views of one participant changed from informed to naïve. P15 showed informed views of the tentativeness of personal explanations in science in the second set of activities and the post-test. After engaging in the second set of activities (Q2), P15 showed informed views of the tentativeness of personal explanations in science and considered that changing positions regarding a scientific issue like fluoridation is possible when the scientists who support the opposing claim provide more convincing evidence as shown in the excerpt below:

If scientists supported model B with more data, they might change my position regarding this issue (P15, Q2)

However, after engaging in the third set of activities (Q3) in the context of electromagnetic wave pollution, her views changed from informed to naïve views. She explained that scientists do not change their positions when they consider their claim, as shown in the excerpt below:

Changing position regarding an issue is not possible when the claim seems logical while the alternative claim shows negative consequences (P15, Q3)

P15 did not respond to the question after the fourth set of activities (Q4). On the other hand, in the post-test, she showed informed views of the tentativeness of personal explanation in science again and thought that people might change their opinions when scientific knowledge changes and more relevant information support a certain opinion as illustrated in the excerpts below:

If there were more logical information or something that would let me change my mind I would because everything about a certain topic would change with time (P15, post)

Moreover, variation of NOS views was shown in different NOS themes. The NOS views of the participants changed from informed to intermediary views, mostly when discussing the validity of the information. Out of sixteen participants, eleven showed variation of views from informed to an intermediary view (Table 19). Variation cases appeared the least (only two cases) when discussing ethical issues in science. The reason may be that the majority of the participants did not respond to the question regarding ethical issues in science in the post-test. In the post-test, the participants were asked to express their views of ethical issues in science in general and not regarding a specific context. In the absence of a specific context, the concepts of ethical issues may have seemed too abstract for the participants.

Table 19

Number of Variation Cases in each of the NOS Theme

NOS Theme	Number of Variation cases
Validity of Information	11
Relationship between Science and Economics	7
Tentativeness of Personal Explanations in Science	7
Tentativeness of Scientific Knowledge	6
Scientific Practices and Knowledge Construction	6
Relationship between Science and Social Organizations	5
Relationship between Science and Politics	4
Differences in Views in Science	3
Relationship between Science and Society	3
Ethical Issues in Science	2

CHAPTER V

DISCUSSION

This study aimed to investigate the changes in grade 7 learners' NOS understandings and argumentation skills after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues. Moreover, it intended to relate participants' alternative information evaluation and argumentation skills after engaging in reflective discussions from the perspective of FRA. This chapter is divided into three parts organized by research questions. The first part presents a summary and a discussion of the research findings regarding both NOS and argumentation skills. The second part discusses the results regarding the relationship of information evaluation and argumentation skills. The third part presents the limitations of the study, while the fourth part discusses recommendations for both future research and practice.

Discussion of Results

First Research Question: Changes in grade 7 learners' NOS understandings and argumentation skills after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues.

The discussion of the first research question includes three sections. The first section discusses the changes in the participants' NOS views; the second section discusses the changes in participants' abilities to formulate arguments and counterarguments. The third section discusses the Variation in NOS views identified throughout the research study.

Changes in NOS Views

The results of this research study showed that after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues, more participants developed informed views of the ten themes of NOS targeted in this research study. In the pre-test, the participants were not able to provide informed views of the tentativeness of personal explanations in science, the validity of information, scientific practices, and knowledge construction. Moreover, the participants in the pre-test were not able to relate science to society, politics, economics, social organizations, and ethical issues in science. Most participants did not express any conception about these themes and did not answer questions related to those themes. Throughout the intervention, the number of participants not responding to the questions decreased, and more participants were able to express ideas to relate politics, economics, social organizations, and ethical issues to science. Throughout the research study, most of the participants gradually developed more informed views of the ten NOS themes. In the post-test, more than half of the participants showed informed views of the tentativeness of scientific knowledge (62.5%), differences in views (87.5%), scientific practices and knowledge construction (75%), the relationship of science and society (56.2%), politics (50%), economics (62.5%) and social organizations (62.5%) (Table13). However, the number of participants having informed views of the validity of information (25%) and ethical issues (0%) dropped in the post-test compared to the previous open-ended questionnaires.

The detailed analysis of responses and the preparation of the profiles allowed the researcher to identify commonalities among the changes in the participants' NOS views and helped her to discover the patterns regarding variations of NOS views in similar contexts.

The analysis of changes in NOS views by each participant showed that after engaging reflective discussion and alternative information evaluation activities in four different contexts of socio-scientific issues allowed nearly half of the participants (51.87%) to develop informed views of the ten targeted NOS themes. More participants expressed their views throughout the research study reducing the number of participants who did not respond to the questions. Remarkably less number of participants provided naïve views (9.37 %) in the post-test.

Analysis of Table 14 also shows that there was a steady increase in the informed views of participants in 7 out of the ten targeted themes (Tentative scientific knowledge, differences in views, scientific knowledge construction, relationship between science and society, relationship between and politics, relationship between science and economics, relationship between science and social organizations). However, for two themes, Tentative personal explanations and validity of information), views of all participants ‘changed to intermediary, while the views of a portion of the participants changed to informed. Finally, for the theme “ethical issues in science,” the majority of participants stayed at the naïve level.

The inconsistency of the views regarding the validity of information and the ethical issues in the post-test and those of the previous open-ended questionnaires could be due to the contexts in which these issues were addressed. In the post-test, the participants gave examples of the ethical issues and specific ideas about the validity of information, which were discussed in the previous sets of activities in the contexts of water fluoridation, electromagnetic wave pollution, and animal testing. However, they were unable to elaborate these more abstract conceptions in their responses of the post-test in the absence of a specific context. Moreover, the number of participants showing informed views of the relationship between science, politics, and economics dropped only after the fourth set of activities (Q4) in the context of animal testing. The number of participants showing informed views increased again in the post-test.

Analysis of changes in NOS views demonstrated that context plays a remarkable role in expressing NOS views. For example, fewer participants were able to describe the relationship between science, politics, and economics in the context of animal testing, which is an unfamiliar context for students compared to the other socio-scientific issues. Furthermore, in the pre- and post-test, as the participants were asked to relate science to ethical issues in general and not in a specific context, fewer participants showed informed views of NOS regarding the relationship of science with these themes. The results showed that participants were able to express more informed views about abstract notions such as the validity of information and ethical issues in a specific context such as climate change, water fluoridation, and electromagnetic wave pollution.

The results regarding the inconsistency of responses about the validity of information, ethical issues, politics, and economics were in line with Khishfe and Abd-El-Khalick (2002) and Khishfe (2012), who have shown that participants expressed more informed understandings of NOS when addressing a more familiar topic. These results were also consistent with Zeidler Walker, Ackett and Simmons, (2002), Sadler, Chambers, and Zeidler (2004), and Khishfe (2012), who showed that SSI-based instruction improves students' NOS understandings. The results of this study confirmed claims of prior studies (Feinkohl et al. 2016; Ferguson et al. 2012; Trautwein & Lu dtke 2007) who argued that epistemic beliefs may be developed and shaped by exposing students to opposing information and suggest that the epistemic cognition of individuals may take place when they are engaged in discussing the opposing beliefs in the context of controversial issues.

Although the results were inconsistent only in the validity of information and ethical issues themes, in general, the engagement of the participants in information evaluation activities and reflective discussions remarkably improved participants' views of NOS. As the participants evaluated information on the websites about controversial social issues in terms of the currency criterion, the participants developed more informed views regarding the tentativeness of scientific knowledge and the tentativeness of the personal explanations. They realized that scientific information presented in articles published a long time ago might not be so relevant or valid as scientific information is subject to change due to discoveries and enhanced technology. As the participants evaluated the websites, which described the positions of the proponents and the opponents regarding a certain controversial issue, in terms of accuracy, they developed more informed views of the validity of information and differences in views among scientists. They became aware of the importance of evidence for ensuring the validity of information and recognized the differences in views among different scientific communities. Highlighting the importance of checking multiple resources during the information evaluation activities allowed the participants to realize that various sources may present different points of view based on the authors' differences in background knowledge, experiences, and benefits. The participants realized that in certain circumstances, individuals support a particular view based on their personal or financial benefits.

Besides, when evaluating alternative information from different websites, the participants were introduced to specific social organizations and associations such as animal rights organizations, associations of dentists, as well as food and water quality controlling organizations. This allowed them to relate science to social organizations, associations, and NGOs. The participants were able to explain the role of these organizations in society and their contribution to scientific issues. Moreover, in many cases of information evaluation practices, the arguments of animal or human rights associations helped the participants to reflect on the ethical issues related to science. For example, the descriptions of the suffering of animals during animal testing allowed many participants to consider the ethical and moral aspects of scientific practices. In other cases, evidence that showed the adverse effects of water fluoridation and electromagnetic waves, for example, helped the participants to make judgments and consider certain scientific practices to be unacceptable.

During the reflective discussions, the participants took part in discourses regarding the relationship between science, society, politics, and economics. The teacher used well-designed guiding questions to help the participants reflect on and develop a better understanding of the social, political, and economic issues related to science. The participants showed an understanding of the role of the government in social-scientific several problems. They explained how scientific innovations might help individuals or governments to profit financially. At the same time, they realized how specific scientific products might lead to an increase in unemployment in the country. Most of the participants realized that factories might be closed, and the production of certain products may be banned because of their adverse effects on people or the environment.

On the other hand, they recognized that in many cases, scientific products might replace certain professions and lead to unemployment of the workers in that field. Moreover, the participants developed deeper understandings regarding the positive and negative impacts of science on the health of people in society and their lifestyles. The results of this research study are consistent with previous studies (Abd-El Khalick & Lederman, 2000; Akerson, Abd-El-Khalick, & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002) that show that the development of NOS understandings is more effective and prominent when addressed explicitly in reflective instructional settings.

The results of this research study were consistent with Leung et al. (2015), who argued that critical evaluations to check the credibility of explanations help learners improve their scientific reasoning and their understanding of the nature of scientific knowledge. Moreover, the results confirm that engaging in information evaluation activities allows participants to develop more informed views about NOS and expands their scientific reasoning. This is in line with Hofer (2004), who highlighted the importance of investigating the epistemic development of students during the evaluation of the credibility of alternative explanations and developing interventions for this purpose. The results of this study were also in line with the research study conducted by Sadler, Chambers, and Zeidler (2004), who examined the views of high school students regarding the tentative, empirical, and social aspects of NOS and the ways they evaluate the Global Warming controversial socio-scientific issue. The authors showed that understanding of several aspects of NOS affects the way students understand, evaluate, and debate contradictory evidence regarding socio-scientific issues. They concluded that conflicting views about SSIs provoked students' thoughts of NOS and developed their knowledge about the ways researchers evaluate contradictory evidence. Furthermore, the intervention increased students' awareness regarding social and personal influences on researchers' judgments.

Throughout the intervention, engaging the participants in alternative information evaluation activities as well as reflective discussions regarding the social controversy in the FRA framework allowed them to understand the nature of science more comprehensively and inclusively. The participants were able to interrelate several complex ideas in the contexts of relevant social controversial issues to describe the nature of scientific knowledge and practices. Moreover, they were able to explain the relationship of science with society, politics, economics, social organization, and ethical issues, which are rarely addressed in science instruction. Those results are in line with Erduran and Dagher's beliefs that "students' engagement in learning NOS would be enhanced if the various categories are interrelated in meaningful contexts that go beyond disconnected bits of information" (Erduran & Dagher, 2014b, p 344).

The FRA allowed the participants to comprehend how science is associated with political and economic issues. In many cases, the participants identified the role of science in shaping the minds of governments and people in society and its influence on their decision-making processes. They also targeted how changes in scientific information may lead to financial problems in a country in general and for certain professions in particular. In many contexts, the participants were also able to relate to science and technology. They specified the role of technology in scientific knowledge construction and explained the tentative nature of scientific knowledge due to innovations of technology and the availability of more developed techniques for data collection and analysis. In addition, participants were able to realize the existence of relationships between science and social organizations such as NGOs and associations, as well as to identify the role of these organizations in specific scientific issues. The FRA bridged the gap of diverse fields of science and provided a larger and more comprehensives views of science.

At the beginning of the research study, the majority of the participants were not able to relate science to society, politics, economics, social organizations, and ethical issues. The intervention designed based on the FRA framework remarkably improved participants' understandings of the relationship of science with these other fields. At the end of the research study, the participants showed understandings that constructing scientific knowledge is not only individual work performed by scientists. Instead, they recognized that besides cognitive and empirical practices, scientists develop theories considering ethical issues, social criteria, and peer reviews, as well as writing articles, sharing outcomes with others, and engaging in argumentation. Furthermore, this research study indicates that the FRA framework helped participants to explain different procedures, processes, and actions in science in a more detailed manner. Through FRA, the participants addressed NOS more inclusively as they developed understandings about and related features from several fields of science. These understandings encompassed the distinctive nature of various fields of science and allowed participants to think beyond the objective statements and experimentations of science. The FRA was influential for making contextualized meaning of the NOS and developed informed views regarding the social activities, scientific practices, and communicative ways utilized for constructing scientific knowledge.

The suggestion that the FRA presents an alternative to the consensus view of NOS has been criticized. For instance, it has been alleged that it is too advanced for high school students (Lederman & Lederman, 2014). The results of this research study contradict this argument and show that even middle school students were able to reason about the complex and interrelated scientific notions. Furthermore, Lederman and Lederman (2014) argued that although FRA is formatted as a matrix, it is still just another list of features of science just as the consensus view is. However, Irzik and Nola (2014) responded that this argument misunderstands how the FRA was intended to be used, the results of this research study confirm that FRA categories provide the opportunity for exploring NOS in contextualized and thematic instructional settings because they are dynamically interrelated (Dagher & Erduran, 2017). Moreover, the reflective discussions designed in this research study based on the FRA confirmed that it organizes different features and characteristics of NOS coherently to show how science functions as a system (Dagher & Erduran, 2017).

Changes in Argumentation Skills

Analysis of changes in argumentation skills answered the second part of the first research question. The analysis indicated that, after engaging in reflective discussions following alternative information evaluation in the context of socio-scientific controversial issues, more participants developed Level 3 arguments and counterarguments. In the pre-test, none of the participants was able to formulate Level 3 counterarguments, and only two participants were able to formulate Level 3 arguments. Throughout the research study, most of the participants gradually developed the ability to formulate Level 3 arguments and counterarguments. In the post-test, remarkably, more participants formulated Level 3 (81.2 %) and counterarguments (43.7%) arguments.

However, even though most participants formulated Level 3 arguments after engaging in the second set of activities (Q2), the number of these participants slightly decreased when participants were asked to argue in the context of animal testing. The analysis of changes in argumentation skills showed that context plays a remarkable role in formulating arguments also. The results echoed previous findings (Khishfe, 2012; Lewis & Leach, 2006), who found that participants engaged in more reasoned argumentation when the issue was more familiar to them. The authors found that when the socio-scientific issue was more familiar to students, the participants were able to engage in more reasoned discussions and justifications.

Nevertheless, in general, the participants' argumentation skills improved remarkably, as they engaged in information evaluation activities through MEL-diagrams in the context of SSIs. The structure of the MEL-diagrams allowed the participants to reflect on the argumentation components of Toulmin's argumentation model. The "Model" boxes of the MEL-diagram helped the participants to understand that claims refer to certain positions regarding a specific issue. The presence of more than one opposing Model or claim in the MEL-diagram allowed the participants to differentiate opposing claims regarding the same socio-scientific issue and develop a better understanding of counterarguments. The "Evidence" boxes helped the participants to recognize that valid claims are supported by more robust evidence. They also made use of this evidence to support their arguments for several reasons.

The results of this study are consistent with Jiménez-Aleixandre and Erduran (2007), who argued that argumentation, is facilitated when epistemic criteria are used to evaluate scientific information in the classrooms. The authors considered that critical evaluations through epistemic criteria are particularly significant for checking the credibility of evidence regarding a claim in the context of socio-scientific issues, thereby affecting the way individuals argue or defend a certain position. Moreover, as the participants discussed controversial scientific issues, they needed to consider the perspectives of and the solutions suggested by several parties. Therefore, in line with Hsu, Tsai, Hou, and Tsai (2014), the results of this research study showed that the process of addressing socio-scientific issues not only enabled learners to practice evaluating, analyzing and reflecting on information actively but also led them to use higher-order reasoning and reflective thinking and engaged them in justifying claims or arguments to make decisions accordingly.

In the research study conducted by Lombardi et al. (2016), grade seven students evaluated the plausibility of information individually without having any communication with their peers or their teacher. The researchers suggested conducting future research studies that include collective argumentation in parallel with plausibility evaluation to investigate the effect of collaborative argumentation discussions on students' ability to interpret the link between evidence and claims. Moreover, Ford (2012) highlighted the importance of operating science classrooms similar to the scientific community. Considering the suggestions of these previous studies, the intervention of this research study was designed to engage students in reflective discussions and collaborative argumentation and to practice science.

The design of the intervention of this study was also in line with Christodoulou and Osborne's (2014) suggestions who suggested that educators have to engage students in knowledge-generating practices similar to scientists such as argumentation, modeling, discourse, and critique instead of directly telling them what science is or how it works. The participants practiced evaluating information using data provided about the source of information utilizing specific argumentation skills for identifying the strengths and shortcomings of the alternative explanations and considering the evidence presented to support the reason. For example, during the discussions and collaborative argumentation, a number of the participants experienced convincing one of their classmates, who was with animal testing, through supporting their arguments with robust evidence to change in his views. Therefore, activities that include evaluation of information related to controversial science issues or socio-scientific issues were a practical way to bring about discussions and debates on the development of science and scientific knowledge (Yaung, Chen, and Tsai, 2013). Justifying and evaluating claims were two of those knowledge-generating practices that have to be incorporated in the instruction as "science-as-practice" (Ford, 2012).

Reflective discussions designed based on the FRA framework also helped the participants to reflect on social, political, economic, and ethical issues regarding the controversial social issues and helped the participants to use these notions as reasons to support their arguments. The awareness of the participants about these aspects of scientific knowledge and practices expanded their thinking and strengthened their arguments. It seems that evaluation activities promote mature scientific and reflective thinking (Lombardi et al., 2016) and support argumentation. In reflective discussions, when the teacher asked learners to justify and explain their answers, the learners went beyond providing claims to backing them up with justifications (Ford & Wango, 2012). They were enabled to perceive science as involving epistemic practices, as well as to appreciate the role of these practices and discourse in the process of scientific knowledge construction. Sandoval and Morrison (2003) also highlighted the importance of engaging learners in epistemic discourse that includes engaging learners in discussions during which they argue about why and based on what criteria they support a certain justification as well as explain the importance of evidence in their justifications. Christodoulou and Osborne (2014) considered the evaluation, comparison, and justification as effective practices for promoting epistemic discourse in science classrooms. For this reason, this study included evaluating information, comparing the alternative views, and justifying them through argumentation. In science education, argumentation is highly associated with epistemic discussions. Argumentation was viewed as a negotiation where the students engaged in discourse and evaluate errors to come up with evidence-based arguments at the end (Chen et al., 2016; Nussbaum & Edwards, 2011). Discussions about the nature of knowledge and knowing, which are promoted through argumentation practices, enable students to consider argumentation as a practice for generating knowledge instead of accumulating facts (Christodoulou & Osborne, 2014). Ford (2012) addresses the ways of making sense of scientific information and suggests that argumentation is an approach that facilitates sense-making. Scientists understand many phenomena while they take part in argumentation procedures. Therefore, argumentative practices and discourse are the foundation of scientific claims.

Variation in NOS Views

Throughout the analysis process of NOS views, the researcher found several cases of participants returning to a former or less developed state, which we identified as “Variation” in NOS views. Analysis of changes in NOS views by participants demonstrated several Variation cases. Although, in general, NOS views of the participants developed throughout the research study, the development was not consistent for many participants. In several instances, the NOS views of the participants changed throughout the pre-test, Q1, Q2, Q3, Q4, and the post-test. Mostly, the NOS views returned to intermediary views after providing informed views of NOS previously. One of the reasons for the Variation could be due to the context of the controversial social issue. In more familiar contexts, such as climate change and water fluoridation, the participants exhibited more informed views of NOS compared to non-familiar contexts, such as animal testing. In the context of animal testing, the Variation rate was higher than the other contexts of controversial social issues. In the context of animal testing, fewer participants showed informed views of scientific practices and knowledge construction, the relationship between science and society, politics, and economics.

Second Research Question: The relation between participants' alternative information evaluation and argumentation skills after engaging in reflective discussions from the perspective of FRA.

The Relationship between Alternative Information Evaluation and Argumentation Skills

Analysis of the relationship between information evaluation and argumentation skills allowed the researcher to answer the second research question. The results indicated that there is a very low correlation between the scores of MEL-diagrams, through which the participants evaluated alternative information, and the level of the arguments formulated by the participants. In several cases, participants who scored low on MEL-diagrams formulated Level 3 arguments, while those who scored high grades on information evaluation, formulated Level 1 arguments. In other cases, participants scoring the same in alternative information evaluation formulated arguments of different levels.

This result could be due to the factthat the scores of the MEL-diagrams were assessed based on Lombardi's rubric. In several cases, most of the participants scored lower than expected on the MEL-diagrams because they linked the evidence boxes that support an alternative model and are not related to the targeted model as evidence that contradicts the model. That is, they considered the evidence that supports model A, for example, as evidence, that contradicts model B (and not like it has nothing to do with Model B). The participants considered that the evidence that supports a specific claim contradicts the other claim and serves as a counterargument. These links were considered as wrong based on Lombardi's rubric, and eventually, lower scores of MEL-diagram completion were recorded.

Nevertheless, in general, the average scores of the alternative information evaluation through the MEL-diagrams and the ability of the participants to formulate Level 3 arguments improved throughout the research study. The results of this study are in line with Lombardi et al. (2016), who claimed that explicit and reflective instruction of critical evaluations improves students' implicit judgments related to the credibility of information regarding complex and controversial scientific issues.

As the participants developed more informed views of NOS throughout the study, they also improved their alternative information evaluation skills. The results of this research study are in line with several studies (e.g., Feinkohll et al., 2016; Kolstø 2001; Kuhn & Weinstock 2002; Norris, 1995; Ryder 2001; Sadler et al. 2004; Strømsø et al. 2011) that showed that students' epistemic views guide critical evaluations. That is, individuals with more complex scientific epistemologies evaluate information more critically (Feinkohl et al., 2016). In this regard, Sadler et al. (2004) also claimed that NOS influences the way students evaluate and interpret the supportive evidence related to socio-scientific issues.

Even though the scores of information evaluation increased from 4.50 to 6.50 as the participants engaged in the first three sets of activities (Q1, Q2, and Q3) in the contexts of climate change, water fluoridation, and electromagnetic wave pollution respectively, the alternative information evaluation scores dropped in the context of animal testing to 5.00. Analysis of changes in information credibility evaluation skills also demonstrated that context plays a remarkable role in evaluating information. The analysis of participants' abilities in evaluating alternative information showed that although the participants' abilities in information evaluation improved throughout the research study, the average of the score dropped in the context of animal testing (Table 15). It is possible that animal testing was an unfamiliar context for the participants, and therefore they were not able to evaluate information as efficiently as in those contexts that were more familiar to them.

Limitations

This research study has several inevitable limitations., Even if the sample size of this research study is large enough to describe the phenomena addressed in the research questions, the generalizability of the findings is limited to some extent. It is important to state as well that the volume of data and time constraints did not allow the researcher to analyze the responses of all the participants in detail. Only the responses of three randomly selected participants were analyzed in a detailed manner.

Another limitation is that the intervention period might have been shorter than needed to promote the development of more informed views of NOS, argumentation skills, and alternative information evaluation skills among the students. Although the intervention took place over four weeks during physics, chemistry, and biology sessions, still, this allocated time may not have been enough for some participants to develop more informed views of NOS or better argumentation and evaluation skills. Some of the participants were reluctant to respond to many of the questions because they were afraid to provide incorrect or irrelevant answers. Despite continuous encouragement, these students preferred to avoid answering several questions. Also, some participants, especially at the end of the intervention, did not take the tasks seriously and did not complete the MEL-diagrams and the questionnaires as required. A longer intervention might have helped the learners to get used to the demands of the intervention, thus reducing the hesitation to answer the questions. Nevertheless, within a short period, the majority of the participants were able to develop informed NOS views and improve their argumentation skills remarkably.

Another limitation is the utilization of the POSE questionnaire for collecting data regarding NOS as pre- and posttest. The POSE questionnaire did not provide data regarding many categories of the FRA wheel. Consequently, the researcher adapted the questionnaires and added questions regarding the relationship of science to society, politics, economics, ethical issues, and social organizations.

An additional possible limitation may be that the results are limited to the socio-scientific contexts within which the intervention was implemented. Since the familiarity of the participants with the socio-scientific issues affected their NOS views, argumentation and information evaluation skills, utilization of other socio-scientific and more familiar scientific topics could have given different results. To alleviate this problem, the researcher provided brief explanations about the controversial issues before the evaluation activities to ensure that the participants understand the issue and its controversy.

Another limitation of the study is the efficacy of the teacher in running reflective discussions. Although the researcher trained the teacher and provided the guiding questions of the reflective discussions, in some cases, the teacher was not flexible enough to ask further appropriate questions that challenge students' ideas and lead them to reflect and explain their conceptions comprehensively. Consequently, the researcher trained the teacher again after the first set of activities to ensure that the teacher runs the rest of the discussions more effectively.

Finally, the results of this study showed a low correlation between students' ability to evaluate the MEL-diagrams and their ability to formulate arguments. That is, the results showed that students who scored low grades on MEL-diagram evaluations were not necessarily formulating weak arguments. These results could be due to the rubric that was adopted from Lombardi (2016) and used to score the MEL-diagram evaluations. However, unlike this research study, Lombardi's research did not include argumentation. Therefore, the participants in Lombardi's research study did not have a background in developing counterarguments. Moreover, students chose to link the evidence of a specific model with an arrow that represents that "the evidence has nothing to do with the model." Whereas, this study was performed in the context of argumentation, where the participants have developed conceptions about counterarguments. Therefore, students have considered that evidence that supports a specific model serves as a counterargument for the alternative model. Therefore, based on their conceptions of a counterargument, even if the evidence is not related to the targeted model, the students considered that this evidence contradicts the model. For this reason, the participants lost points and scored lower than expected in the MEL-diagram evaluations. Therefore, it is important to develop a rubric for the MEL-diagrams that are solved in the context of argumentation.

Implications for Practice

Engaging students in alternative information evaluation activities and reflective discussions helped learners to develop more informed NOS views, improved their argumentation skills, and helped them to read and evaluate alternatives more critically. The findings of this study may help educators to plan their instructional approaches and design engaging lessons that allow students to engage in the instruction and practice science. Therefore, educators may select a specific social controversial issue that is related to physics, chemistry, or biology topics and prepare MEL-diagrams using data from websites that show the contradictory positions regarding that controversial issue. Integrating MEL-diagram evaluations, collaborative argumentation, and reflective discussions help educators to make science instruction relevant and meaningful to the students. Incorporating information credibility evaluation, epistemic discussions, and argumentation in science instruction not only motivates students and contributes to teaching essential life skills of the 21st-century but also provides the opportunity for learners to evaluate different perspectives, engage in critical reasoning, practice decision making, and argue about contradictory scientific claims, as well as to develop moral and ethical values regarding controversial social issues.

As the findings of this research study highlight the importance of information credibility skills in developing better epistemological understanding, it draws the attention of the librarians and computer or technology teachers to contribute to developing students' information literacy. The results of this study give school librarians the responsibility of converting libraries into more attractive places in the current environments where digital information is dominant. It invites both librarians and technology teachers to design programs and prepare activities to teach students information evaluation skills and support science teachers in this crucial task.

The findings of this study show that designing similar instructional activities based on the FRA framework allows students to develop a more comprehensive view of NOS and, consequently, to several aspects of a scientifically literate person. The results of this study draw the attention of curriculum designers, to incorporate learning outcomes regarding information evaluation and argumentation in curricula to contribute in preparing scientifically literate individuates who can discuss and make decisions about daily concerns and themes that encompass science (PISA, 2015; Sadler, 2011), to develop "functional scientific literacy" (Zeidler & Keefer, 2003) to acquire reasoning skills needed to address socio-scientific issues, to read and comprehend scientific reports and reflect critically on information (PISA, 2015), to develop an informed and comprehensive understanding of NOS, and to value the interdependence of science, technology, environment, and society.

The implementation of similar practices in science instructions indirectly contributes to the civic education of the students. Moreover, reflective argumentation, information credibility evaluation, and other decision-making skills in the context of socio-scientific issues are most importantly needed for preparing informed and active citizens who take an active role in their communities. Students' awareness about climate and environmental issues, water, and food quality, as well as health issues and their readiness to evaluate and argue regarding these issues, contributes to reaching sustainable development goals. These skills are particularly crucial for the Lebanese students as Lebanon faces many socio-scientific problems, including the electricity and garbage crisis, quality of food and water, and environmental issues. Therefore, the results of this research study urge curriculum and textbook designers to introduce objectives regarding information evaluation skills and to include objectives that target the development of NOS views comprehensively in the Lebanese curriculum.

Recommendations for Future Research

This study has made a unique contribution to the field in that it is possibly one of the earliest studies conducted to utilize the FRA framework to design interventions applied in classrooms. According to the literature review conducted for this study, studies that have used the FRA framework to design science instructions for K-12 students are lacking. Most of the research studies conducted previously used the FRA framework to analyze curricula, textbooks, and teacher education programs. Therefore, more research is required to study the effectiveness of the FRA framework in designing science instructions and in promoting not only students' comprehensive NOS views but also other skills such as argumentation. However, future research studies planning to use the FRA framework are encouraged to develop a questionnaire that includes items regarding the FRA categories. The available questionnaires that aim to collect data about individuals' NOS views do not include all the categories included in the FRA. Future researchers may use the questionnaire developed particularly for FRA to ensure that the objectives of their research study are aligned with their data collection instruments.

One of the identified limitations of this study was the limited duration of the intervention. Consequently, research is needed with longer interventions to increase the generalizability of the results. A more extended intervention might help the learners to get used to the demands of the intervention, thus reducing the hesitation to answer the questions. Furthermore, since this research study only covered four social-controversial issues, future research must focus on other different socio-scientific issues and compare the students' performance in the contexts of familiar and unfamiliar controversial issues.

Nevertheless, the finding of this study and those in the literature review show that information evaluation practices are highly associated with NOS views and argumentation skills. Therefore, similar to the relation of alternative information evaluation and argumentation skills examined in this study, it is interesting to further study the relationship between the alternative evaluation skills and NOS views in each NOS theme. Future studies may examine if students who have developed better alternative information skills have also developed more informed views of NOS Unlike this research study, which included the detailed analysis of only three randomly selected participants of similar changes in NOS views, future studies have to consider analyzing the responses of participants of extreme cases that did not show similar patterns of NOS views. These research studies may find out the reasons that restricted some participants from developing informed views at the end of the research study. Moreover, other research studies may investigate the possibility of improving students' NOS views at different grade levels and designing a vertical progression for information evaluation skills, argumentation skills, and NOS views. Moreover, the findings showed that in several cases, students' views returned to a former or less developed state of NOS views. Although it was clear from the results that the context of the socio-scientific issue impacted the Variation of the NOS views, it is interesting to study further the reasons for the variation in NOS views

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APPENDICES

APPENDIX I

DESCRIPTION OF SOCIO-SCIENTIFIC ISSUES

Scenario I: Climate Change

Climate change refers to significant, long-term changes in the global climate. These changes mainly include an increase in the average temperature of the atmosphere (Global Warming), an increase in rainfall, a decrease in arctic ice due to melting, and an increase in the level of seawater. Climate change is a controversial issue. Alternative explanations are given regarding the causes of climate change. On the one hand, a group of people believes that human activities have led to climate change through an increase in the amount of greenhouse gases liberated in the atmosphere due to burning large amounts of fossil fuels. Greenhouse gases, such as carbon dioxide and water vapor, trap the heat of the earth from the sun in the atmosphere, prevent it from radiating out into space and cause an increase the atmospheric temperature. On the other hand, another group of people argues that changes in the climate and increase in the temperature of the atmosphere are due to the increase in the amount of heat received from the sun. This has created an imbalance between heat incoming and radiating out of the earth. When equal flow of heat takes place to the earth and then back to the space, Earth's temperature maintains equilibrium. However, when this equilibrium is disturbed and the amount of incoming or outgoing heat increases or decreases, global temperatures rise or fall in response.

Scenario II: Water Fluoridation

The fluoridation of water involves adding Fluoride to public drinking water. This issue is controversial and has been the causeof many court cases. The group in favor of water fluoridation considers fluoridation as a safe and inexpensive way to prevent tooth decay for all citizens during their lifetime. They point out that many distinguished national and international scientific organizations support fluoridation. Further, this group argues that scientific research shows that water fluoridation reduces tooth decay and cavities and prevents dental disease. The group against fluoridation considers it unethical because it is a form of involuntary medication; it violates people's rights, as they have no choice. They also point out that fluoridation does not have FDA approval. Further, this group argues that scientific research shows the harmful effects of fluoridation, such as possible links to cancer.

Scenario III: Animal Testing

Animal experiments are widely used to develop new medicines and to test the safety of other products. Many of these experiments cause pain to the animals involved or reduce their quality of life in other ways. This issue is controversial because there are two positions on animal experiments. The group against animal experiments argues that it is morally wrong to cause animals to suffer, then experimenting on animals produces serious moral problems. Moreover, they consider that the benefits of animal testing to human beings are not proven. Any benefits to human beings that animal testing does provide could be produced in other ways. On the other hand, the group in favor of animal testing argue that during experiments, the suffering is minimized. Moreover, they consider that animal testing is effective because human benefits are gained which could not be obtained by using other methods

Scenario IV: Electromagnetic Wave Pollution

Everywhere in the modern world, the vibration of alternating current generates electromagnetic waves — from the television, the blender, the light bulbs, the wires in the wall. People are exposed to a great number of electromagnetic waves as they are emitted around them. This is a social controversial issue because people have different positions regarding the exposition of people to electromagnetic waves. A group of people argues that electromagnetic waves cause diseases such as cancer and infertility. On the other hand, another group of people claims that electromagnetic waves do not cause harm to living things.

APPENDIX II

ONLINE ARTICLES UTILIZED FOR THE PREPARATION OF THE MEL-DIAGRAMS.

Proponents of "Water Fluoridation"

"Facts about Fluoridation" by Douglas Main

Posted on LiveScience.com on April 30, 2015

URL: https://www.livescience.com/37123-fluoridation.html

Opponents of "Water Fluoridation"

"How seriously should we take the fluoride controversy?" by Adam Wernick

Posted on Public Radio International (PRI) website on December 05, 2015

URL: https://www.pri.org/stories/2015-12-05/how-seriously-should-we-take-fluoride-controversy

Proponents of "Animal Testing"

"Defending animal research" by Lorna Collier published by APA in July/August 2014, Vol 45, No. 7

URL: http://www.apa.org/monitor/2014/07-08/defending-research.aspx

Opponents of "Animal Testing"

"Experiments on Animals: Overview" by Francis S. Collins posted on the PETA's website

URL: https://www.peta.org/issues/animals-used-for-experimentation/animals-used-experimentation-factsheets/animal-experiments-overview/

Animal experimentation: A difficult issue" posted on the BBC website

URL: http://www.bbc.co.uk/ethics/animals/using/experiments_1.shtml

Proponents of "Electromagnetic Waves"

"Nonsense about the Health Effects of Electromagnetic Radiation" by Harriet Hall

Posted in Science-Based Medicine website on January 15, 2013.

URL: https://sciencebasedmedicine.org/nonsense-about-the-health-effects-of-electromagnetic-radiation/

Opponents of "Electromagnetic Waves"

"Debate Continues on Hazards of Electromagnetic Waves" by Kenneth Chang.

Posted on New York Times website on July 7, 2014

URL: https://www.nytimes.com/2014/07/08/science/debate-continues-on-hazards-of-electromagnetic-waves.html?mcubz=0

The position of those who consider Climate Change is caused by the increase in Sun's energy

"Climate and Earth's Energy Budget" by Rebecca Lindsey

Posted on NASA Earth Observatory website on January 14, 2009

URL: https://earthobservatory.nasa.gov/Features/EnergyBalance/page1.php

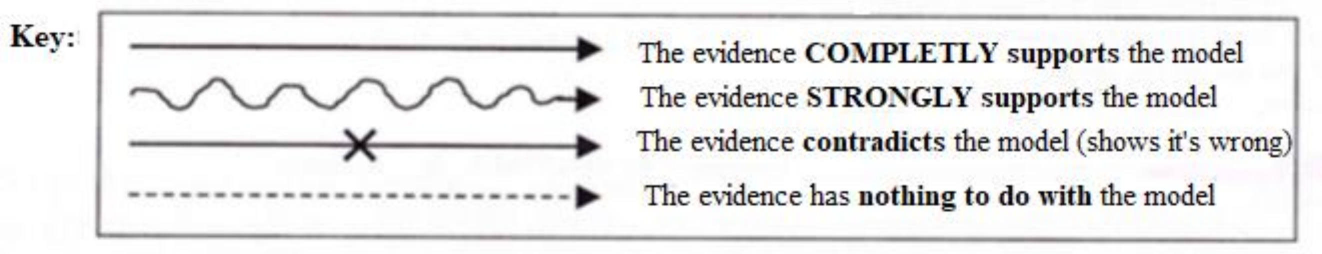
The position of those who consider Climate Change is caused by the increase in human activities

"A Blanket around the Earth" by Sultan Zafar

Posted on NASA Global Climate Change website on 24, December 2015

URL: https://climate.nasa.gov/causes/

APPENDIX III
MEL-DIAGRAMS OF SOCIO-SCIENTIFIC ISSUES



Climate Change MEL Diagram

Directions: Use the key box above to draw two arrows from each evidence box, one to each model. You will draw a total of 8 arrows.

Evidence #1:

Atmospheric greenhouse gas concentrations have been rising for the past 50 years. Human activities have led to greater release of atmospheric gases.

Model A

Our current climate change is caused by the increasing amount of gases released by human activities.

Evidence #3:

Satellites are measuring more of Earth's energy being absorbed by the greenhouse gases.

Evidence #2:

Solar activity has decreased since 1970. Lower activity means that Earth has received less of Sun's energy. But Earth's temperature has continued to rise.

Model B

Our current climate change is caused by the increasing amount of energy released by the Sun.

Evidence #4:

Increases and decreases in global temperatures closely matches with the increases and decreases in solar activity before industrial revolution.

Provide a reason for three of the arrows you have drawn. Write your reasons for the three most interesting or important arrows.

1. Write the number of the evidence you are writing about.
2. Circle the appropriate word (strongly supports, supports, contradicts, has nothing to do with)
3. Write which model you are writing bout.
4. Then write your reason.

Evidence # ________ (strongly supports, supports, contradicts, and has nothing to do) with Model ____ because:

Evidence # ________ (strongly supports, supports, contradicts, and has nothing to do) with Model ____ because:

Evidence # ________ (strongly supports, supports, contradicts, and has nothing to do) with Model ____ because:

Answer the following questions.

1. Based on what do you think different scientists support different views regarding this controversial issue. What makes scientists support a certain view? (empirical)
2. After you linked the evidence to the models, explain if the provided data is valid enough for you to take a position regarding this issue?) (empirical)
3. What is your view/opinion regarding this controversial issue? Do you support Model A or Model B? (Claim)
4. Explain and justify your position. (Data/evidence)
5. Your classmates disagree with your position. What explanation do they give to support their position and persuade you? (counterargument)
6. Do you think you may change your position regarding this issue? Why? (tentative)
7. Do you think scientists change their minds? Why? (tentative)

Animal Testing MEL Diagram

Directions: Use the key box to draw two arrows from each evidence box, one to each model. You will draw a total of 12 arrows.

Evidence #1:

Animal experiments eliminate some potential drugs as either ineffective or too dangerous to use on human beings. They will produce such great benefits for humanity that it is morally acceptable to harm a few animals.

Evidence #2:

The level of suffering and the number of animals involved are both so high that the benefits to humanity don't provide moral justification.

Evidence #3:

The majority of animal experiments do not contribute to improving human health, and the value of the role that animal experimentation plays in most medical advances is questionable.

Model A

Animal Testing is acceptable and necessary for experimentations.

Model B

Animal Testing is unacceptable and immoral.

Evidence #4:

Diseases that are artificially induced in animals in a laboratory, whether they be mice or monkeys, are never identical to those that occur naturally in human beings. And because animal species differ from one another biologically in many significant ways, it becomes even more unlikely that animal experiments will yield results that will be correctly interpreted and applied to the human condition in a meaningful way. Although at least 85 HIV/AIDS vaccines have been successful in nonhuman primate studies, as of 2015, everyone has failed to protect humans.

Evidence #5:

Rodent brains are made of the same mechanisms as human brains — the same kind of cells, the same kind of neurotransmitters or chemicals. There's no hope for developing medicines or interventions or treatments for the brain and for psychological functioning until you first understand the process by which the brain works.

Evidence #6:

In the future, experimenting on cell cultures instead of whole animals, using computer models and studying human volunteers are possible ways to replace animal testing.

Provide a reason for three of the arrows you have drawn. Write your reasons for the three most interesting or important arrows.

1. Write the number of the evidence you are writing about.
2. Circle the appropriate word (strongly supports, supports, contradicts, has nothing to do with)
3. Write which model you are writing bout.
4. Then write your reason.

Evidence # ________ (strongly supports, supports, contradicts, and has nothing to do) with Model ____ because:

Evidence # ________ (strongly supports, supports, contradicts, and has nothing to do) with Model ____ because:

Evidence # ________ (strongly supports, supports, contradicts, and has nothing to do) with Model ____ because:

Answer the following questions.

1. Based on what do you think different scientists support different views regarding this controversial issue, what makes scientists support a certain view? (empirical)
2. After you linked the evidence to the models, explain if the provided data is valid enough for you to take a position regarding this issue. (empirical)
3. What is your view/opinion regarding this controversial issue? Do you support Model A or Model B? (Claim)
4. Explain and justify your position. (Data/evidence)
5. Your classmates disagree with your position. What explanation do they give to support their position and persuade you? (counterargument)
6. Do you think you may change your position regarding this issue? Why? (tentative)
7. Do you think scientists change their minds? Why? (tentative)

Water Fluoridation MEL Diagram

Directions: Use the key box to draw two arrows from each evidence box, one to each model. You will draw a total of 16 arrows.

Evidence #1:

The new recommendation, issued in 2015, for the optimal fluoride level that should be in drinking water to prevent tooth decay is for a single level of 0.7mg of fluoride per liter of water, opposed to the 0.7 to 1.2 mg/l recommendation issued in 1962, which is now

Evidence # 2:

A 2009 study that tracked fluoride exposure in more than 600 children in Iowa found no significant link between fluoride exposure and tooth decay.

Evidence # 3:

There is a link between high fluoride levels found naturally in drinking water and lower IQs in children.

Evidence #4:

Adding a small amount of additional fluoride helps prevent tooth decay.

Model A

Fluorine prevents tooth cavity.

Model B

Extra Fluorine intake causes health problems (hypothyroidism, declination of IQ level, neurological dysfunction...)

Evidence #5:

Only three studies since 1975 have established credible links between fluoridated water and cavity

Evidence # 6:

There hasn't been a lot of really good-quality research looking at the negative effects of water fluoridation

Evidence # 7:

Swallowing fluoride with every drink of water could interfere with neurological development and thyroid. There is possible association between fluoridated water and underactive thyroid, or hypothyroidism, earlier this year.

Evidence #8:

Fluoride can prevent tooth decay when applied topically (toothpastes, rinses etc.). Fluoride that isn't swallowed doesn't carry the potential health risks to IQ and the thyroid.

Provide a reason for three of the arrows you have drawn. Write your reasons for the three most interesting or important arrows.

1. Write the number of the evidence you are writing about.
2. Circle the appropriate word (strongly supports, supports, contradicts, has nothing to do with)
3. Write which model you are writing bout.
4. Then write your reason.

Evidence # ________ (strongly supports, supports, contradicts, and has nothing to do) with Model ____ because:

Evidence # ________ (strongly supports, supports, contradicts, and has nothing to do) with Model ____ because:

Evidence # ________ (strongly supports, supports, contradicts, and has nothing to do) with Model ____ because:

Answer the following questions.

1. Based on what do you think different scientists support different views regarding this controversial issue, what makes scientists support a certain view? (empirical)
2. After you linked the evidence to the models, explain if the provided data is valid enough for you to take a position regarding this issue. (empirical)
3. What is your view/opinion regarding this controversial issue? Do you support Model A or Model B? (Claim)
4. Explain and justify your position. (Data/evidence)
5. Your classmates disagree with your position. What explanation do they give to support their position and persuade you? (counterargument)
6. Do you think you may change your position regarding this issue? Why? (tentative)
7. Do you think scientists change their minds? Why? (tentative)

Electromagnetic waves MEL Diagram

Directions: Use the key box to draw two arrows from each evidence box, one to each model. You will draw a total of 16 arrows.

Evidence # 1:

Electromagnetic waves are harmless because they are too weak to knock out electrons and directly damage molecules in the body.

Evidence #2:

On July 11, 1989, Science Times reported the ubiquitous background radiation cause cancer.

Evidence # 3:

An epidemiological study comparing children in Denver who died of cancer from 1950 to 1973 with a control group of other children found that those who lived near electrical distribution lines were twice as likely to develop the disease as those who did not.

Evidence #4:

The symptoms of electro pollution-induced sickness involve all organs with many weakening symptoms, from skin rashes to cancer. This invisible poison wrecks human brains, causes sperm to deteriorate, ovaries to malfunction, and fetus to die

Model A

Electromagnetic waves cause infertility, cancer and other diseases.

Model B

Electromagnetic waves do not harm the body

Evidence # 5:

A dairy farmer a quarter of a mile away noticed that his cows started producing ten pounds more milk a day because the dirty electricity was being removed from the ground currents.

Evidence # 6:

Based on 25,000 articles published over the past 30 years, Current studies do not confirm the existence of any health consequences from exposure to low level electromagnetic fields

Evidence # 7:

Electromagnetic radiation, particularly the magnetic part of it, changed some functioning in cells and altered the action of neurotransmitters. There appears to be an increase in leukemia rates with long-term exposure to magnetic fields stronger than 0.4 microtesla.

Evidence # 8:

Looking at trends over the last 20, 30 years, we don't see an increase in cancer. But again, we don't know. If it takes cancer 10 years to promote, maybe we will see it in the next 10 years.

Provide a reason for three of the arrows you have drawn. Write your reasons for the three most interesting or important arrows.

1. Write the number of the evidence you are writing about.
2. Circle the appropriate word (strongly supports, supports, contradicts, has nothing to do with)
3. Write which model you are writing bout.
4. Then write your reason.

Evidence # ________ (strongly supports, supports, contradicts, and has nothing to do) with Model ____ because:

Evidence # ________ (strongly supports, supports, contradicts, and has nothing to do) with Model ____ because:

Evidence # ________ (strongly supports, supports, contradicts, and has nothing to do) with Model ____ because:

Answer the following questions.

1. Based on what do you think different scientists support different views regarding this controversial issue, what makes scientists support a certain view? (empirical)
2. After you linked the evidence to the models, explain if the provided data is valid enough for you to take a position regarding this issue. (empirical)
3. What is your view/opinion regarding this controversial issue? Do you support Model A or Model B? (Claim)
4. Explain and justify your position. (Data/evidence)
5. Your classmates disagree with your position. What explanation do they give to support their position and persuade you? (counterargument)
6. Do you think you may change your position regarding this issue? Why? (tentative)
7. Do you think scientists change their minds? Why? (tentative)

APPENDIX IV

LESSON PLANS

First Session: Instruction and Practice

Purpose

This lesson will introduce the participants to information credibility evaluation and argumentation. They will be introduced the criteria for credibility evaluation and three components of Toulmin's model of argumentation. The participants will also be acquainted with MEL-diagrams and their completion procedures.

Instructional Objectives

By the end of the lesson, the participants will be able to:

- Evaluate the credibility of information in terms of currency and accuracy.
- Identify three components of Toulmin's model of argumentation
- Develop arguments based on Toulmin's model
- Complete MEL-diagrams

Background Knowledge

Understanding the Greenhouse effect and the types of energy received from the Sun facilitates participants' comprehension of MEL-diagram.

Materials Needed

iPads

Climate Change MEL-diagram worksheet

Instructional Activities

The teacher will review the ideas discussed Global Warming as the participants researched about its causes throughout the unit. The teacher will remind the participants about the controversy of climate change and discuss the alternative explanations represented in different online sources. The teacher will highlight the importance of evaluating the credibility of the information.

The teacher will introduce the two criteria for information evaluation: Currency and Accuracy. He will explain that the “currency” criterion refers to how up-to-date is the information, while “accuracy” refers to how valid, well researched, and supported by evidence is a piece of information.

The teacher will ask the participants to open the following online articles on their iPads.

The position of those who consider Climate Change is caused by the increase in Sun’s energy

“Climate and Earth’s Energy Budget” by Rebecca Lindsey

Posted on NASA Earth Observatory website on January 14, 2009

URL: https://earthobservatory.nasa.gov/Features/EnergyBalance/page1.php

The position of those who consider Climate Change is caused by the increase in human activities

“A Blanket around the Earth” by Sultan Zafar

Posted on NASA Global Climate Change website on 24, December 2015

URL: https://climate.nasa.gov/causes/

The teacher will guide the participants to practice evaluating the online articles in terms of currency. In order to evaluate the socio-scientific issues in terms of accuracy, the teacher will explain to the participants how to complete a MEL-Diagram. He will also explain the different types of boxes included in the MEL-diagrams (Model boxes and Evidence boxes

The teacher will provide a brief description of the controversial issue about Climate Change (see-Appendix I) and ask the participants to read it. He will assist the participants in completing the MEL- diagram about Climate Change by explaining what each type of arrow means. He will ask them to practice drawing arrows to link the Evidence to the Models. Later, the teacher will give directions to the participants and assist them in completing the explanatory part of the MEL-diagrams.

The teacher will describe an argument and relate it to science. As the participants are acquainted with the components of the MEL-diagrams, the teacher will highlight three argumentation components from Toulmin's model (Claim, Evidence, and Rebuttal) and link them to the MEL-diagrams. The teacher will explain that the "Model" represented in the MEL-diagrams refers to the "Claim" of Toulmin's model, which is a position regarding the socio-scientific issues. The evidence provided to support the positions refers to the "Data" component of Toulmin's model. Finally, the two alternative explanations represented by the opponents and proponents (Model A and Model B) of the same socio-scientific issue represent the "Rebuttal" component of Toulmin's model. The evidence provided includes data that oppose the claims stated in each model. Therefore, the statements that oppose a certain position or a model are referred to as the rebuttal component of Toulmin's model of argumentation.

Second Session: Instruction and Practice

Purpose: This lesson will engage the participants in reflective discussions on the relationship of political, social, and economic issues to science, as well as on argumentation components of Toulmin's model.

Instructional Objectives

By the end of the lesson, the participants will be able to.-

- Identify the components of a scientific argument
- Describe the relationship of political, social, and economic issues to science.
- Develop their own arguments regarding climate change

Background Knowledge

This lesson does not require any background knowledge because the participants need to express only their thoughts about a topic related to their daily lives.

Materials Needed

Climate Change MEL-diagram Questionnaire

Instructional Activities

The teacher will review the criteria for evaluating the credibility of information and the three components of argumentation. Then, he will engage the participants in a reflective discussion referring to the discussion questions listed in Appendix V. He will allow the participants to share their ideas and debate, as well as will discuss the social and ethical values that are involved in the climate change controversial issue.

After engaging in reflective discussions, the teacher will assist the participants in responding to the MEL-diagram Questionnaire (see Appendix III).

Third Session: Animal Testing Controversial Issue

Purpose: This lesson will give the opportunity of evaluating information in terms of currency and accuracy criteria. It will also introduce the controversial issue related to animal testing through the animal testing MEL-diagram. The teacher will provide a brief description of the controversial issue about Animal Testing (see-Appendix I) and ask the participants to read it.

Material

iPads

Animal Testing MEL-Diagram worksheet

Instructional Objectives

By the end of the lesson, the participants will be able to.-

- Identify the components of a scientific argument
- Describe the relationship of political, social, and economic issues to science.
- Develop their arguments regarding animal testing

Background Knowledge

This lesson does not require any background knowledge because the participants need to express only their thoughts about a topic related to their daily lives

Instructional Activities

The teacher will discuss with the participants that killing animals is not done only by natural predators. Humans also harm and kill animals in the process of performing medical tests on them. Animal testing has its advantages and disadvantages. He will introduce the controversy of animal testing.

The teacher will ask the participants to open the following online articles on their iPads.

Proponents of “Animal Testing”

“Defending animal research” by Lorna Collier published by APA in July/August 2014, Vol 45, No. 7

URL: http://www.apa.org/monitor/2014/07-08/defending-research.aspx

Opponents of “Animal Testing”

“Experiments on Animals: Overview” by Francis S. Collins posted on the PETA’s website

URL: https://www.peta.org/issues/animals-used-for-experimentation/animals-used-experimentation-factsheets/animal-experiments-overview/

Animal experimentation: A difficult issue” posted on the BBC website

URL: http://www.bbc.co.uk/ethics/animals/using/experiments_1.shtml

The teacher will review the criteria for evaluating the credibility of information (currency and accuracy) and ask the participants to evaluate the websites in terms of currency. In order to evaluate the online articles in terms of accuracy, the teacher will ask the participants to complete the first two stages of the MEL-Diagram about animal testing by drawing the arrows according to the given directions.

Fourth Session: Animal Testing Controversial Issue

Purpose: This lesson will engage the participants in reflective discussions on the relationship of political, social, and economic issues to science, as well as on argumentation components of Toulmin's model.

Instructional Objectives

By the end of the lesson, the participants will be able to.-

- Identify the components of a scientific argument
- Describe the relationship of political, social, and economic issues to science.
- Develop their arguments regarding animal testing

Background Knowledge

This lesson does not require any background knowledge because the participants need to express only their thoughts about a topic related to their daily lives.

Materials Needed

Animal Testing MEL-diagram Questionnaire

Instructional Activities

The teacher will review the criteria for evaluating the credibility of information and the three components of argumentation. Then, he will engage the participants in a reflective discussion referring to the discussion questions listed in Appendix V. He will allow the participants to share their ideas and debate, as well as will discuss the social and ethical values that are involved in the animal testing controversial issue.

After engaging in reflective discussions, the teacher will assist the participants in responding to the MEL-diagram Questionnaire (see Appendix III).

Fifth Session: Water Fluoridation Controversial Issue

Purpose: This lesson will give the opportunity of evaluating information in terms of currency and accuracy criteria. It will also introduce the controversial issue related to water fluoridation through water fluoridation MEL-diagram. The teacher will provide a brief description of the controversial issue about water fluoridation (see-Appendix I) and ask the participants to read it.

Material

iPads

Water Fluoridation MEL-Diagram worksheet

Instructional Objectives

By the end of the lesson, the participants will be able to.-

- Identify the components of a scientific argument
- Describe the relationship of political, social, and economic issues to science.
- Develop their own arguments regarding water fluoridation

Background Knowledge

This lesson does not require any background knowledge because the participants need to only express their thoughts about a topic related to their daily lives

Instructional Activities

Refereeing to the idea that drinking water is a mixture, the teacher will introduce the idea of water fluoridation to the participants. Making and drinking a mixture of fluorine and water has its advantages and disadvantages.

The teacher will ask the participants to open the following online articles on their iPads.

Proponents of "Water Fluoridation"

"Facts about Fluoridation" by Douglas Main

Posted on LiveScience.com on April 30, 2015

URL: https://www.livescience.com/37123-fluoridation.html

Opponents of "Water Fluoridation"

"How seriously should we take the fluoride controversy?" by Adam Wernick

Posted on Public Radio International (PRI) website on December 05, 2015

URL: https://www.pri.org/stories/2015-12-05/how-seriously-should-we-take-fluoride-controversy

The teacher will review the criteria for evaluating the credibility of information (currency and accuracy) and ask the participants to evaluate the websites in terms of currency. In order to evaluate the online articles in terms of accuracy, the teacher will ask the participants to complete the first two stages of the MEL-Diagram about water fluoridation by drawing the arrows according to the given directions.

Sixth Session: Water Fluoridation Controversial Issue

Purpose: This lesson will engage the participants in reflective discussions on the relationship of political, social, and economic issues to science, as well as on argumentation components of Toulmin's model.

Instructional Objectives

By the end of the lesson, the participants will be able to.-

- Identify the components of a scientific argument
- Describe the relationship of political, social, and economic issues to science.
- Develop their own arguments regarding water fluoridation

Background Knowledge

The completion of the electromagnetic wave MEL-diagram is facilitated as the participants are familiar with the nature of electromagnetic waves and their sources.

Materials Needed

Water Fluoridation MEL-diagram Questionnaire

Instructional Activities

The teacher will review the criteria for evaluating the credibility of information and the three components of argumentation. Then, he will engage the participants in a reflective discussion referring to the discussion questions listed in Appendix V. He will allow the participants to share their ideas and debate, as well as will discuss the social and ethical values that are involved in the water fluoridation controversial issue.

After engaging in reflective discussions, the teacher will assist the participants in responding to the MEL-diagram Questionnaire (see Appendix III).

Seventh Session: Electromagnetic Wave Pollution Controversial Issue

Purpose: This lesson will give the opportunity of evaluating information in terms of currency and accuracy criteria. It will also introduce the controversial issue related to electromagnetic wave pollution through the animal testing MEL-diagram. The teacher will provide a brief description of the controversial issue about electromagnetic waves (see-Appendix I) and ask the participants to read it.

Material

iPads

Electromagnetic Wave MEL-Diagram worksheet

Instructional Objectives

By the end of the lesson, the participants will be able to.-

- Identify the components of a scientific argument
- Describe the relationship of political, social, and economic issues to science.
- Develop their arguments regarding electromagnetic wave pollution

Background Knowledge

This lesson does not require any background knowledge because the participants need to express only their thoughts about a topic related to their daily lives

Instructional Activities

The teacher will review the types of heat transfer (conduction, convection, and radiation). He will explain again that radiation is the emission of energy in the form of electromagnetic waves and give examples of electromagnetic wave emissions in daily life, such as the microwaves, Wi-Fi routers,,etc. The teacher will discuss that electromagnetic wave emission has its advantages and disadvantages.

The teacher will ask the participants to open the following online articles on their iPads.

Proponents of "Electromagnetic Waves"

"Nonsense about the Health Effects of Electromagnetic Radiation" by Harriet Hall

Posted in Science-Based Medicine website on January 15, 2013.

URL: https://sciencebasedmedicine.org/nonsense-about-the-health-effects-of-electromagnetic-radiation/

Opponents of "Electromagnetic Waves"

"Debate Continues of Electromagnetic Waves" by Kenneth Chang.

Posted on New York Times website on July 7, 2014

URL: https://www.nytimes.com/2014/07/08/science/debate-continues-on-hazards-of-electromagnetic-waves.html?mcubz=0

The teacher will review the criteria for evaluating the credibility of information (currency and accuracy) and ask the participants to evaluate the websites in terms of currency. In order to evaluate the online articles in terms of accuracy, the teacher will ask the participants to complete the first two stages of the MEL-Diagram about electromagnetic wave pollution by drawing the arrows according to the given directions.

Eight Session: Electromagnetic Wave Pollution Controversial Issue

Purpose: This lesson will engage the participants in reflective discussions on the relationship of political, social, and economic issues to science, as well as on argumentation components of Toulmin's model.

Instructional Objectives

By the end of the lesson, the participants will be able to.-

- Identify the components of a scientific argument
- Describe the relationship of political, social, and economic issues to science.
- Develop their arguments regarding electromagnetic wave pollution

Background Knowledge

This lesson does not require any background knowledge because the participants need to express only their thoughts about a topic related to their daily lives.

Materials Needed

Electromagnetic Wave MEL-diagram Questionnaire

Instructional Activities

The teacher will review the criteria for evaluating the credibility of information and the three components of argumentation. Then, he will engage the participants in a reflective discussion referring to the discussion questions listed in Appendix V. He will allow the participants to share their ideas and debate, as well as will discuss the social and ethical values that are involved in the electromagnetic wave controversial issue.

After engaging in reflective discussions, the teacher will assist the participants in responding to the MEL-diagram Questionnaire (see Appendix II).

APPENDIX V

SAMPLE OF REFLECTIVE DISCUSSION QUESTIONS

General Questions

1. Why is the "currency" criterion important for evaluating information?
2. Do you think that some models are more valid and well researched than others? Explain your answer
3. How do you think did the proponents of each model came up with their conclusions?
4. Why do alternative explanations regarding the same socio-scientific issue exist?
5. What are some reasons that may convince people or lead them to change their position regarding an issue?
6. Why is it important to check for multiple resources to confirm the credibility of the argument/information?

Climate Change MEL Diagram

1. Why do you think the opponents of Model A try to persuade that climate change is not caused by the greenhouse gases released by human activities (such as factories, cars …)?
2. How do you think political and economic interests are related to this issue?
3. What relationships do you find between science, politics, and economics?
4. What do you think social organizations must do?

5. Do you think science plays an important role in environmental, social, and economic issues? Why? Give examples.

Animal Testing MEL Diagram

1. Why do you think the supporters of Model A find animal testing acceptable?
2. What are the aims of animal testing?
3. Do you think animal testing is the only method of experimenting with drugs/vaccines and understanding the process of disease development? Why?
4. What alternative methodologies do you suggest?
5. What do you think organizations that defend animal rights must do?
6. How can you explain the role of science in improving people's health and quality of life?
7. Do you think scientific practices must respect the moral and ethical values? Why?

Water Fluoridation MEL Diagram

1. Considering the new recommendations of Fluorine level in drinking water, how do you think scientific knowledge develops? Do you think scientific knowledge changes? Why?
2. How can you explain the role of science in improving people's health and quality of life?
3. Some scientists tell that there is not enough evidence to confirm that high levels of Fluorine affect humans negatively. What do you think scientists have to do?
4. Do you think it is ethical to force the citizens to intake excess fluorine? Why?
5. How do you relate science to ethical and moral issues?

Electromagnetic Wave MEL Diagram

1. Why do you think the supporters of Model B try to persuade people that electromagnetic waves do not harm people?
2. What do you think are their economic interests?
3. How do you think science, technology, and society are related?
4. How can you explain the role of science in improving people’s health and quality of life?
5. Do you think it is ethical to force the citizens to be exposed to electromagnetic waves? Why?

APPENDIX VI

PERSPECTIVES ON SCIENTIFIC EPISTEMOLOGY (POSE) QUESTIONNAIRE

1. Scientists produce scientific knowledge (facts, laws, and theories). Some of this knowledge is found in your science textbooks. How do scientists produce scientific knowledge?
2. Do you think that the scientific knowledge found in your science textbooks (facts, laws, and theories) will change in the future?

Circle one: Yes [Answer part (a) if you circled ‘‘yes’’].

No [Answer part (b) if you circled ‘‘no’’].

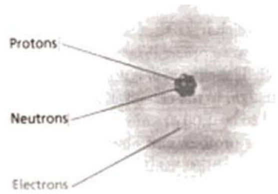
(a) If you circled ‘‘yes,’’ explain why you think scientific knowledge will change in the future.

(b) If you circled ‘‘no,’’ explain why you think scientific knowledge will not change in the future.

3. Scientists believe that the dinosaurs lived more than 65 million years ago.
1. How do scientists know that dinosaurs really existed?
2. How can scientists tell how the dinosaurs look like (for example, the texture and color of dinosaurs’ skin, the shape of their eyes)?
3. (c) How confident are scientists about the way they believe the dinosaurs look like?
4. What does the word “evidence” mean to you?
5. (b) What does the word “data” mean to you?
6. (c) What ways do scientists use to collect “evidence” or “data”?

7. (d) Why do scientists collect “evidence” or “data”?

8. All matter is made up of atoms. Atoms are very small: even a single cell is made up of millions and millions of atoms. The atom is shown as having a nucleus in the center with electrons moving around it.



Scientists hold **different** views about this representation of the atom. Some scientists believe that this is a true and exact representation of the atom. Other scientists believe that this representation is just a model since we cannot know whether this representation of the atom is true and exact.

1. What is your view on this issue? Why do you hold this view?
2. How do scientists determine the representation of the atom shown above?

(c) Scientists **disagree** about their beliefs regarding the representation of the atom. How is it possible for scientists to disagree? Explain your answer.

3. Scientists agree that about 65 million years ago the dinosaurs became extinct. However, scientists disagree about what caused this extinction. Some scientists believe that and violent volcanic eruptions were responsible for the extinction of the dinosaurs. Scientists believe that a huge comet (or asteroid) hit the earth 65 million years ago and led a series of events that caused the extinction.

(a) Did you hear about this issue before? Circle one: Yes No

(b) What, if any, is your view on this issue? Why do you hold this view?

4. Does it surprise you that scientists disagree about the cause of the extinction of the dinosaurs? Explain your answer.

5. It is known that all the above scientists have access to and use the **same** set of data. How could it be that these scientists use the same data and still arrive at different regarding the cause of the extinction of the dinosaurs

APPENDIX VII

ARGUMENTATION QUESTIONNAIRE:

GENETICALLY MODIFIED FOOD

Scientists in the United Kingdom have developed a new genetically modified strain of 'golden rice' to deal with Vitamin A deficiency. The genetically modified rice plants contain two extra genes. One group of scientists believe that eating genetically modified rice with the two extra genes can help prevent blindness by improving vitamin A intake during digestion. As a result, this could help reduce childhood blindness, which affects 500,000 children worldwide each year, especially in developing countries in Asia. This group argues that no studies have indicated any dangers associated with genetically modified foods. Another group of scientists argues that we do not know how eating genetically modified rice (or any food) will affect us. There is no biochemical analysis of the golden rice to see how adding two genes may have changed the plant as a whole. Additionally, this group is concerned that the new rice is grown in the same regions as other rice, so there might be crossing over (contamination), which would change the genetic material of other rice. Therefore, these scientists argue that a healthily balanced diet would be a better solution than the golden rice to deal with Vitamin A deficiency.

(a) Do you think the golden rice should be produced and marketed? YES NO

(b) Explain and justify your decision

(c) Another scientist, Professor Ponso, disagrees with your decision. How could he explain his position to illustrate the reasons supporting it and convince you?

(d) What would you reply to Professor Ponso to explain that your decision is right?

(e) Do you think the knowledge about genetically modified food might change in the future? Explain why or why not.

(f) Do you think you might change your decision in the future? Explain why or why not

(g) Is there anything else you would want to know about this issue that might help you decide or even change your decision?

APPENDIX VIII

FRA Analytical Framework

		FRA Wheel Category	Informed	Intermediary	Naïve
	Cognitive-Epistemic Aspects (CE)				
CE	**Themes I used in my study**	**Aims & values**	Cognitive values of objectivity, novelty, accuracy or empirical adequacy		
	The validity of information	accuracy or empirical adequacy	The student mentions that scientific knowledge is based on logical and conceptual connections between evidence and explanations. That is, the participant explains the importance of the currency of evidence and the importance of checking multiple resources to validate the knowledge.	The student recognizes the importance of evidence for supporting a certain explanation.	The student does not recognize the connections between evidence and explanations. The student does not recognize the importance of evidence in supporting a certain explanation.
	The tentativeness of personal explanations in Science	Changing own ideas in light of evidence	The student realizes the need to change their own ideas in light of the evidence and proceeds to do so. Change in ideas and positions are possible when environmental factors change with time.	Student realizes that there is new evidence that disconfirms own ideas but does not engage with it	The student is not responsive to new evidence that challenges his/her ideas to change

			People change their minds when enough strong evidence is provided to get convinced by the alternative positions.		
	The tentativeness of scientific knowledge	Searching for new explanations	The student mentions two or more of the following: The student understands that science seeks new explanations because new explanations contribute to knowledge. Scientific explanations are subject to revision and improvement in light of new evidence Science findings are frequently revised and/or reinterpreted based on new evidence Scientific knowledge changes when scientists change the way they think and get convinced of another view. Scientific knowledge changes as external (environmental) factors change with time. Advances in technology influence the progress of science and science has influenced advances in technology	The student understands that new explanations are desired by scientists but does not quite appreciate the significance of new knowledge in science	The student does not understand that scientists' new explanations contribute to knowledge.
	Differences in views	Recognizing	The student understands that the opposite point	The student understands that the	The student does not

		opposite ideas	of views exist and elaborates with reasons for the differences in views such as having different background knowledge and experiences, as well as different ways of thinking and benefits	opposite point of view exists without providing reasons for the existence of these ideas.	understand that the opposite point of view exists.
	Scientific knowledge Construction and Practices	**Practices**	Scientific practices are addressed, such as the purpose for investigation, nature of the investigation, mode of data analysis, development of a model, predictive or explanatory function of a model		
		Methods	Different methods are addressed such as Experimental, hypothesis testing, observations, calculations		
		Knowledge	Addresses different forms of knowledge such as models, theories, laws in terms of their predictive and/or explanatory functions		
			The student mentions that science investigations use a variety of methods and tools to make measurements and observations and find to develop knowledge in terms of theories, models, and laws.	The student mentions that scientists perform experiments to find new knowledge using the equipment and making calculations.	The student mentions that scientists perform experiments to find new knowledge
	Social-Institutional Aspects: (A) internal to science (inner circle); (B) external to science (outer circle)				
		FRA Wheel Category	**Informed**	**Intermediate**	**Naïve**
SI-A		**Social Certification**	Through engagement with peers in the scientific community, scientific findings get reviewed, criticized, and evaluated.		

	Scientific knowledge construction and practices	**Professional Activities**	Scientists engage in such activities as attending conferences, presenting findings, publishing findings, writing research proposals, seeking funding and reviewing papers as well as grant applications		
			The student mentions that scientists share their information with other scientists, engage in argumentation, and come up to an agreement after engaging in debates. Scientists publish their findings.	The student mentions that scientists share their data to evaluate it.	The student doesn't mention any of the informed views on social certification and professional activities
	Ethical Issues in Science	**Scientific Ethos**	This refers to intellectual honesty, respect for research subjects, respect for the environment, freedom, and openness. Also, integrity, carefulness, openness, respect for intellectual property, confidentiality, responsible publication, responsible mentoring, respect for colleagues, social responsibility, non-discrimination, competence, legality, animal care, human subjects' protection.		
			The student mentions two or more views regarding scientific ethos such as science respects the environment or avoids causing harm to people and animal, ensure people's freedom by providing choices to people regarding scientific issues	The student states one informed view of science ethos.	The student doesn't mention any of the informed views
	Relationship between Science and Society	**Social Values**	Respecting the environment, social utility (Social utility refers to the use of scientific knowledge to humankind. Does the book portray this image of scientific work as having an ultimate social purpose?		

			The student states two or more relations between science and society because it affects the environment and peoples' lifestyles.	The student states one relationship between science and society.	The student does not relate science and society to each other.
SI-B	**Relationship between Science and Economics**	**Financial Systems**	Discloses the role of funding and funding agencies, commercial and special interests in controlling or limiting scientific knowledge		
			The student states two or more informed views to relate science to financial systems.	The student states one informed view that related science to financial systems.	The student does not relate science and financial systems to each other.
	Relationship between Science and Politics	**Political Power Structures**	The relevance of colonial ambitions to the historical or current context; ideological influences; relationship to in and extra state politics		
			The student mentions that governments influence scientific issues by making decisions regarding them and contributes to science by funding scientific researches.	The student mentions that governments have contributed to scientific issues and make decisions regarding those issues.	The student does not relate science and politics to each other.
	Relationship between Science and social organizations, NGOs, associations	**Social Organizations and Interactions**	Relays how scientists work among their peers within and across the organizational structures		

			The student mentions that social organizations, associations, and NGOs organize campaigns to influence the government’s or people’s decisions and behavior. They raise awareness to find solutions to social problems, to protect the rights of animals or humans.	The student states one informed view that related science to social organizations, associations, and NGOs.	The student does not relate science and any of the social organizations, NGOs or associations