Science & Education (2023) 32:361–380
https://doi.org/10.1007/s11191-021-00318-8

ARTICLE

Facilitating Middle School Students' Reasoning About Vaccines

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Accepted: 17 December 2021 / Published online: 4 March 2022

Abstract
In a pandemic era, it is necessary to equip individuals with the ability to make informed decisions about health issues, especially in relation to viruses and vaccines. In order to achieve this goal, science educators need to explore students' decisions and reasoning about vaccination. The aim of the study reported in the paper, therefore, is to explore eighth graders' reasoning about vaccination throughout a 4-week implementation of small group and plenary discussion of false claims about vaccinations. The implementation consisted of a five-phase procedure including teacher presentation of false claims and related evidence texts about vaccination, small group discussions, a plenary discussion, and finally, an introduction to valid scientific content about vaccination. The explanations of the representatives from each group during the plenary discussion were video-taped and analyzed by the researchers independently to examine student decisions on each claim. Another data source of this study included student interviews in which the researchers videotaped and analyzed eight interviewees' responses. The findings revealed that including well-informed students in small group and plenary discussions may have a positive impact on other students' reasoning. This result indicated the benefit of encouraging students to provide evidence about vaccines during small group and plenary discussions in terms of their reasoning. The implications of this study suggest the necessity of emphasizing on scientific knowledge as well as argumentation for further investigations of students' reasoning on vaccination.

1 Introduction

With the rise of postmodernism, a post-truth culture has explicitly started to emerge as a threat to truth. McIntyre (2018) stated that post-truth was the forerunner of what happened to science for several decades. In the post-truth era, it is often possible for people to encounter misinformation, especially on controversial issues. False or misleading information encountered during a pandemic is called an infodemic (WHO, 2021). The infodemic

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which has spread with the current COVID-19 pandemic constitutes an important stage in terms of showing the effects of post-truth. These effects can be exemplified as: denying scientific results without any robust evidence or denying science because it is not compatible with one's ideological, political, financial, or religious views (McIntyre, 2018). Due to the complex nature of scientific knowledge, it is difficult to identify misinformation because it requires people to have knowledge of more than one specific scientific discipline (Sharon and Baram-Tsabari, 2020). Although misinformation about these subjects is in circulation, people need to make decisions about science-related social issues (Dawson & Venville, 2020) and controversial issues (Lee & Brown, 2018). When people make decisions on an issue, many variables affect their decisions. Kovaka (2019) listed the variables that cause science denial as the lack of knowledge about scientific facts, poor reasoning, and social or political identity. Science denial has become a major threat to human health and civilization (Hansson, 2017) on the topics such as vaccination and global climate change (Barzilai & Chinn, 2020). The scope of this study, thus, is vaccination, one of the most salient phenomena of science denial in the past few years.

In recent years, as it has all around the world, the vaccine rejection movement has been rising rapidly in Turkey. There are various claims containing fallacies such as *argumentum ad hominem* and *non sequitur* in circulation about the effects and purposes of vaccines (Petousis-Harris, et al., 2010). A considerable number of people tend to believe in fallacies, false claims and misleading information and reject being vaccinated. Romijnders et al (2019) showed that vaccine refusers are more prone to accept anecdotal evidence when making decisions about vaccines. Refusers provide inadequate reasoning and problem-solving skills to support their decision. Therefore, it is necessary to educate individuals who make informed decisions and use adequate reasoning to critically evaluate claims about issues that will affect their health preferences (Rennie et al., 2001).

In order to make informed decisions about personal and social issues, people need to acquire scientific literacy. Scientific literacy has emerged as an important goal in both making informed decisions and dealing with misinformation. From this perspective, it is necessary to redefine scientific literacy. The National Academies' report (2016) listed following seven components of scientific literacy: (i) foundational literacies, (ii) content knowledge, (iii) understanding of scientific practices, (iv) identifying and judging appropriate scientific expertise, (v) epistemic knowledge, (vi) cultural understanding of science and (vii) disposition and habits of mind. From this point of view, the argument of this paper is that it is necessary to investigate students' content knowledge and reasoning about scientific issues, especially for those about which a lot of misinformation is spread throughout the world.

Hodson (2021) broadened the scientific literacy perspective by pointing out the necessity of accessing required scientific knowledge, developing media literacy to access related information, improving political awareness, critical evaluation and ethical understanding of controversial socio-scientific issues. We argue here that it is crucial to examine students' reasoning about issues that are controversial in the public domain such as vaccines.

Wang et al. (2019) emphasized that misinformation on health-related issues such as vaccines and infectious diseases has high prevalence and popularity on social media. During the pandemic, this popularity and misinformation on vaccination increased. Scientifically literate people who can critically evaluate misinformation on social media and make informed decisions on health-related issues should be able to resolve uncertainty in science. This ability requires individuals to understand the social aspects of scientific practices including argumentation, discourse, peer review and social certification as well as epistemic aspects of scientific practices, such as collecting and analyzing data, interpreting scientific findings, and activities including observation, classification and experimentation

in the generation, evaluation and revision of scientific knowledge (Erduran & Dagher, 2014). From this perspective, it is important to incorporate discussion and debates about health issues in science classrooms from middles school grades and above.

Whilst there is a large consensus within the scientific community on a majority of controversial issues, results of scientific research are not certain. The misinformed individual's understanding of science tends to consider scientific results as certain and often overlooks the uncertainty that is inherent in science (Kampourakis & McCain, 2019). Similarly, young students also think that scientific knowledge is certain and has clear-cut processes (Akerson & Volrich, 2006).

In a post-truth world and with the advancement of technology, misinformation is spreading rapidly through digital media. In such a world, evidence-based evaluations and informed decision-making requires an understanding of uncertainty. This type of understanding involves not only accepting psychological uncertainty, but also epistemic and social uncertainty. For this purpose, K12 science education should provide students with the opportunities to learn how to productively manage uncertainty and comprehend how scientific knowledge develops (Kampourakis & McCain, 2019). Barnes and Church (2013) concluded that proponents of creationism and proponents of evolution may have very different epistemological commitments on understanding the nature of science (NOS). Therefore, they stressed the necessity of focusing on the NOS in primary and secondary schools. Similar to evolution, the use of vaccines in teaching can be an important opportunity for students to practice their skills in managing and dealing with scientific uncertainty.

Maia et al. (2021) also emphasized the importance of the discussion and communication in and of science, especially discussion that is directed in the public domain and reflects the uncertainty of science. From this point of view, discussing and communicating claims about vaccines in science classes, especially emphasizing the uncertain nature of science, may be helpful to increase students' understanding and reasoning about science.

In order to deal with uncertainty, students need to understand the experts' evidentiary practices, such as evaluating evidence strength. Epistemic knowledge may be taught by enabling students to appreciate that misinformation originates from poor strength of evidence (Sharon and Baram-Tsabari, 2020). Employing dispositions and habits of mind to make accurate judgments and evaluate arguments through evidentiary practices promotes laypersons' ability to detect misinformation (Sharon and Baram-Tsabari, 2020). It is necessary, thus, to teach students to form beliefs based on good reasoning and being intellectually careful (Barzilai & Chinn, 2017) instead of those that are comforting and reassuring (Sharon and Baram-Tsabari, 2020).

Students' understanding of how science works and how scientists develop scientific understanding of natural phenomena is extremely important both for being a scientifically literate person and for their protection against post-truth savvy. Although transferring uncertainty in science to the K-12 classroom is thought to be problematic because students are not familiar with the purpose of scientists, the results of the studies show that students in elementary schools are able to deal with uncertainty management when their teachers support them. Therefore, it is crucial to let students comprehend their peers' arguments before constructing an argument or criticizing their peers' arguments to resolve uncertainty (Chen, 2020).

Science education practices in schools accept that students are able to make informed decisions by eliminating the lack of knowledge on controversial issues. Although science content knowledge is an important factor, errors in reasoning and identity also affect decision-making. Current educational practices can put students at risk to believe in misinformation unintentionally (Sharon and Baram-Tsabari, 2020). Therefore, the boundary

between misinformation and information becomes unclear for individuals. Individuals have difficulties in evaluating the information they encounter and making decisions based on this information (Oxman and Garcia, 2020). The researchers of this study argue that these deficiencies could be overcome through deliberate attempts by applying appropriate methods in teaching health issues in middle school. As previously mentioned, having scientific content knowledge is not enough to make informed decisions. Educating students to make informed decisions about health is also one of the main goals of science education (Arnold, 2018). Promoting decision-making skills requires individuals to think and argue on daily phenomena (Zeidler & Kahn, 2014). Being aware of the variables that affect decision making such as reasoning errors and biases will guide people to make informed decisions. However, formal curriculum does not give plentiful attention to the identification of errors in reasoning (Tseng, 2018). There is a need for young people to recognize scientific issues that affect society (Dawson & Venville, 2020). Therefore, the researchers aimed to explore students' reasoning about a socioscientific issue, namely vaccines, in a context where the discussion of false claims about vaccines in the classroom was used.

In the case of vaccines, it seems to be useful to let children discuss fallacies, false claims, misleading information and scientific knowledge based on evidence to enable them to achieve the aforementioned components of scientific literacy and to make informed decisions. From this perspective, the researchers of this study argue that employing false claims through a five-phase teaching method may be useful in understanding the aforementioned deficiencies and shed light on science education literature. The research question of the present study is as follows: "What is middle school students' reasoning about vaccination?"

2 Theoretical Framework

Examining the decision-making skills of middle school students regarding vaccination is important to demonstrate how students deal with and recognize errors in their reasoning. Therefore, it is necessary that theoretical and background knowledge about the anti-vaccine movement and anti-vaccine fallacies be introduced.

2.1 Anti-vaccine Movements

We posit that there are two incidents that have led to the spread of the anti-vaccination movement among the public in the twentieth century. The first of these events can be considered as an accident according to the conditions of the period, and the second as a scientific fraud. The first of these is the Cutter Incident, which was named after the laboratories where the polio vaccines were developed, one of the worst pharmaceutical tragedies in history (Offit, 2005). In the first stage of development of the inactive polio vaccine, Cutter Laboratories gave 120,000 doses of vaccine that actually contained active poliovirus. The vaccinations caused 70,000 children to have mild polio, 200 permanent paralysis and 10 deaths (Boom & Cunningham, 2014). In order to avoid such tragedies, governments and health organizations made phase studies compulsory before vaccines were released to the market, and made manufacturers obtain approval from ethics committees for studies with humans. In spite of this, The Cutter Incident has rightly caused the public to question the

safety of vaccines and contributed to an increase in the anti-vaccination movement that continues today (Berman, 2020).

The second incident is the Wakefield et al. (1998) study, which established a relationship between MMR vaccines and autism, a behavioral disorder. Attempts by further studies to determine the relationship between MMR vaccines and autism have been shown to be inconclusive. The results of a cohort study of two million individuals across five different countries revealed that 80% of the risk of developing autism disorder is accounted for by genetics (Bai et al., 2019). Deer (2011) demonstrated that the findings of this study are a scientific fraud achieved through a series of ethical violations. Despite that, many people from political figures to celebrities and from athletes to ordinary people continue to highlight anti-vaccination claims by citing the content of this study, and misinformation has been spreading throughout the globe ever since.

Before examining the characteristic features of the anti-vaccination movement in Turkey, it is essential to give a brief background about the history of vaccination in Turkey. From the letters written by Lady Montague, wife of the British ambassador, to her friends in 1717, it is understood that the variolation technique, which was the precursor of vaccination, was successfully applied in the Ottoman Empire in the eighteenth century (Riedel, 2005). It was recorded that institutions that produced vaccines were established both during the Ottoman dynasty and during the Republic of Turkey, and the society was heavily vaccinated against diseases such as diphtheria, smallpox, tetanus, pneumococcus, typhoid, and pertussis (Turkish Medical Association, 2021). In modern day Turkey, with the widespread use of social media, information about vaccines reaches individuals mostly through platforms where anti-vaccine activists actively spread their messages (Kata, 2012). The anti-vaccine movement in Turkey has been rising since the last decade, especially after the court decision in 2015 that the administration of vaccines was subject to parental consent (Gür, 2019). In the context of Turkey, anti-vaxxers object to vaccines because they are worried about vaccine safety. They argue that vaccines are unnecessary because their children are not in the risk group. They also object to vaccines based on religious, philosophical or conspiracy grounds (Aker, 2018). Some people are concerned about the safety of the vaccine because of the side effects of some substances such as thimerosal, aluminum salts, and formaldehyde, which are included in the vaccine and add properties such as resistance, protection, and efficacy (Arican, 2018). As the idea, that diseases decrease due to the increase in hygiene and sanitation and that childhood vaccines are unnecessary (Smith, 2017), has become widespread in Turkey, individuals have started to claim that vaccines do not provide protection against infectious diseases and therefore are unnecessary (Arican, 2018). After the Wakefield incident, the anti-vaccine movement in Turkey also mentioned a relationship between vaccines and autism due to the increase in autism prevalence in recent years (Yüksel & Topuzoğlu, 2019). Another reason for the opposition to vaccination is religious reasons. Some argue that according to the Islamic belief substances such as gelatin derived from pigs found in vaccines are *haram* (forbidden) and therefore against religious teachings (Aker, 2018). Others oppose vaccines because of the belief that vaccines are a Western conspiracy. They believe that Western countries are using vaccines to spread infertility in order to wipe out the population of Muslim countries (Arican, 2018). More recently, groups of parents interpret the risk–benefit calculation in favor of anti-vaccine sentiment for various reasons (İkiışık, 2018) and state that they are the only authority to make health decisions for their children leaving behind all the facts and denying scientific evidence.

In order to combat science denialism, it is necessary to define it and recognize its features. Diethelm and McKee (2009) stated that science deniers often commit logical

fallacies and take advantage of errors in reasoning. Hence, by understanding the features of logical fallacies and false claims, these individuals can avoid misinformation and combat science denial.

2.2 Fallacies and False Claims

The human brain is known for its unique properties, but despite this, it can easily be manipulated in reasoning (Lack & Rousseau, 2016). Deceptive arguments used to convince another party are known as fallacies. A fallacy is an error of reasoning in order to make a bad argument appear good (Hurley & Watson, 2018) or a deliberate attempt in order to win an argument and convince the audience. The anti-vaccine movement disseminates misinformation that often contains fallacies, conspiracy theories and false claims especially on social media.

One of the most common false claims from anti-vaxxers is that *vaccines cause autism* because thimerosal is an ingredient in the vaccine. However, despite thimerosal being removed from vaccines, autism rates have not decreased. Thus, anti-vaxxers have started to blame other vaccine ingredients (Gerber & Offit, 2009).

Arguments in order to scare the audience such as recounting the chemical names of ingredients or the name of the low dose toxins in the vaccines and the name of the ingredients used to attenuate microorganisms for the vaccines are examples of the types of fallacies about vaccination. Kata (2012) specifically named this fallacy used for vaccines as the "toxin gambit". Another example of the fallacy is the claim that giving children several vaccines for different diseases at the same time can overload the immune system (Middleton and Wolfe, 2017). However, Offit et al. (2002) calculated that a vaccine contains an average of 100 antigens and that children theoretically have the capacity to respond to approximately 10,000 vaccines at the same time. In addition, with the number of vaccines applied over time, the number of immunological components in vaccines has decreased (Geoghegan et al., 2020).

The arguments that vaccination and the effects of medical drugs are underestimated or ignored and those that explain this effect with irrelevant factors are also among the most common fallacies. These fallacies include claims, such as 'infectious diseases declined with the improvement of sanitation and hygiene conditions, not because of vaccines.' Petousis-Harris et al. (2010) did not deny the importance of hygiene and sanitation but emphasized that such claims do not establish a connection between premise and conclusion.

2.3 Teaching Vaccines

In order to avoid the spread of false claims and misinformation, Arede et al. (2019) suggested targeting children and adolescents who might not have strong emotions about vaccines yet. According to these researchers, children's opinion may be affected by different sources, while adults' risk perception is hard to improve because of their strong emotional connection to the topic of vaccination. From this perspective, it is crucial that students are encouraged to evaluate and discuss information based on evidence.

Tseng (2018) investigated high school students' evaluation of web-based misinformation about vaccination, and suggested providing opportunities for students to enable them to critique information and a greater curricular emphasis on teaching evaluation skills and valid scientific reasoning. In the Turkish curriculum, vaccines are introduced during eighth grade. However, curriculum and research studies in Turkey are lacking in terms of

information about students' reasoning skills and their ability to evaluate misinformation and scientific knowledge. This study aims to fulfil this gap by providing eight graders with the opportunities to evaluate false claims about vaccines in order to explore their reasoning about vaccines. The results of this study may contribute to curriculum development about teaching health issues and to further research aiming to improve middle school students' reasoning about vaccines. To achieve this aim, this study explored eight graders' reasoning about the most common false claims about vaccination.

3 Method

3.1 Participants

Twenty-nine eighth graders (14 females and 15 males) studying in the same class in a public middle school in Turkey participated in this study. The students, most of whom were from working class backgrounds, were mostly suburbanites and inhabitants of the school area. These students have prerequisite knowledge about vaccination including classification of living things, cell structure and function, reproduction, DNA structure and function and genetics. The topics of vaccination, gene therapy, gene transferring, and cloning are among the objectives of the science curriculum published by the Ministry of National Education of Turkey (2018). Therefore, eighth graders were chosen to be the participants for this study.

It is compulsory to attend school throughout K12 levels in Turkey. Turkish students study the first four grades in elementary school, the second four grades in middle school and the third four grades in high school. Students attend the closest school to their address in primary and secondary schools. Unless they move to another location, students generally complete the four years in each level (elementary, middle, and high school levels) all together in the same class. In middle school, students take each course, including science, from teachers who have at least an undergraduate degree from education faculties.

3.2 Procedure

The study presented in this paper is a case study, which explored eighth grade students' decisions about vaccination after a five-phase teaching method. The case of this study is the eighth graders' decisions about vaccination. Thus, the researchers examined eighth graders' decisions about vaccination by implementing a five-phased instruction in science lessons throughout 4 weeks. This instruction included the presentations of false claims about vaccination and texts that contain evidence, small group and plenary discussions on the relationships between claims and evidence, and finally the introduction of scientific knowledge to refute each false claim. The first author was the teacher of these students. He began the lesson by listing the false claims and concluded by presenting the scientific knowledge through critically examining each claim based on the protective function of vaccines as well as the trustworthiness of the sources of claims and evidence. Table 1 illustrates the flow of the instruction on vaccination.

Each phase of the instruction and the student activities for these are presented below:

Listing False Claims on Vaccination. At the beginning of the lesson, false claims (summarized in the Appendix I) about vaccines were presented to the students by the teacher. The claims were reflected on the smartboard one by one, and the students were asked to

Table 1 The flow of the instruction on vaccination

Phases of Instruction	Student activity
Listing false claims on vaccination by the teacher	Brainstorming of ideas
Presentation of evidence texts	Reading texts
Small group discussion	Discussing whether each evidence text supports, contradicts or has nothing to do with each claim in groups of four
Plenary discussion	Explanations of evaluations and decisions of each group by a representative
Introducing scientific knowledge	Comparing each false claim to scientific knowledge based on the information of protection of vaccines, their benefits on individuals and public health, as well as the trustworthiness of sources of information

share what they thought about these claims. The teacher then asked the students to brainstorm their ideas and tried to reveal whether the students agreed with the claim and why they thought so. All students were encouraged to express their opinions and were asked to justify their opinions. Students who thought differently about the same claim were encouraged to discuss, and it was explained that they were expected to convince their classmates by presenting robust reasons. The teacher did not make any explanations regarding the accuracy of the claims throughout the discussion, he acted as a guide to involve all students in the discussion. The listing of false claims and brainstorming of ideas continued for 2 h.

Presentation of Evidence Texts. The teacher presented evidence texts, which contained claims about vaccines that the researchers obtained from various mass media to the students. Five different texts from various mass media containing the anti-vaccine claims (see Appendix II) and five different texts containing the pro-vaccine claims (see Appendix III) were distributed to the students, and they were asked to read them. One of the many evidence texts includes a pro-vaccine text, which includes claims about vaccines and vaccination. The pro-vaccine evidence text responds to each claim by citing scientific literature, presenting statistical data, explaining the working mechanism of the vaccine, and revealing the working principles of the immune system. A reference list is also provided at the end of the evidence text for citations included in the text. Anti-vaccine texts are based on the statements written by a person based on his/her personal internet research. The claims in anti-vaccine texts contain fallacies and conspiracy theories, serious logic and computational errors, inferences from personal experiences and manipulated data, and statements that blame healthcare professionals and scientific researchers. There is no reference to the source of the claims in the aforementioned texts and no reference list. The students were given sufficient time to read all texts and to brainstorm ideas on each one. It took 2 h for the students to read the anti-vaccine and pro-vaccine evidence texts. Week one of this study included the first and the second phases of the instruction.

Small Group Discussion. In the following week, students were asked to form groups of four and evaluate each text of evidence as a group by considering false claims previously presented. Accordingly, the teacher asked the students to make a judgment on the evidence texts and evaluate whether they supported each claim or not. In the second week of the instruction, across a 4-h period, students discussed and evaluated three anti-vaccine and three pro-vaccine evidence texts in groups of four.

Plenary discussion. Each group selected a speaker in order to represent and explain their groups' decision and evaluation on the false claims. The representatives were

encouraged to explain group judgment on the claims and discuss their judgment with other representatives. During the discussions, non-representative students who wanted to express their opinions on conflicting issues also took the floor, expressed their views and contributed to the discussion. The teacher showed his tolerance to everyone to share their opinions without judging any student even if they expressed an unscientific view. However, in order to avoid any misconception or misunderstanding, he introduced scientific knowledge by providing examples of supporting or refuting evidence after each claim in the discussion. In the third week of the instruction, a plenary discussion continued for 4 h during which representative students discussed the group views for each claim.

Introducing Scientific Knowledge. Following the discussion, the teacher compared the claims with scientific knowledge and explained the logical errors by reference to scientific information. The teacher explained the functions of vaccines based on scientific facts. By mentioning the historical development of vaccination, the teacher presented the frequencies of the diseases seen before and after vaccination by supporting them with some visuals. In addition to the effect of vaccination on individuals, its effect on public health was also explained, and the effect of vaccine rejection on public health was exemplified by the up-to-date measles cases. Furthermore, the teacher shared several tips on the reliability of the sources of the information acquired by emphasizing the role of inquiry, expertise, credentials, credibility, and peer review on the construction of scientific knowledge. The last week of the instruction was carried out through 4 h of presentation of scientific knowledge to the students.

3.3 Data Sources

Video Recordings of the Plenary Discussion. The participants of the plenary discussion were videotaped during the plenary discussion on claims and evidence. The researchers independently transcribed all video recordings of the plenary discussion verbatim, then applied content analysis based on the research question on the transcribed text in order to explore whether students changed their decisions during discussion. They analyzed the statements related to each claim one by one, identified the students who agreed or disagreed with the claim, and noted down the statements related to the discussion. They quoted critical comments referring to scientific content and the statements for refuting opponent's claims, and they also quoted problematic comments containing fallacies, conspiracy theories, misinformation or anecdotal evidence made by the participants to probe into their reasoning about vaccination.

Individual Interviews. Four weeks after the end of the instruction, the second author of this study conducted a semi-structured interview with eight students based on their answers and comments during plenary discussion. The students who made critical and problematic comments were selected for the interview. The students who contributed to the discussion while the representatives presented their group views were selected for the interview as well. The interviewer asked them whether they agreed with the same claims and whether they thought the same way as they did during the plenary discussion. She also asked them to justify their answers. Each interview lasted an average of 12 min. All students' responses were transcribed verbatim, and the researchers analyzed students' explanations independently on this transcribed text. The researchers analyzed each interviewee's responses to examine their final judgments at the end of the instruction.

4 Results and Discussion

The consequent sections include the results of the representatives' explanations of the decisions of each group and the interviewees' responses.

4.1 Results of Plenary Discussion

Autism Claim (C1). Half of the representatives supported the claim that vaccines cause autism while half of them denied it. It is interesting to note that one participant (S7) reflected that she had no idea about the relationship between autism and vaccines before reading the texts mentioning this relationship in this lesson and after reading the texts, she thought that there may be a relationship.

Unprotection of Vaccines Claim (C2). Seven out of eight participants disagreed with the claim that vaccines do not protect people against diseases, while only one of them (S3) agreed with this claim. He argued that vaccines do not protect us against the flu, so we cannot claim that vaccines protect us against diseases. One participant (S4) made an interesting comment that vaccines protect us because of advanced technology. Another participant explained that she refused to be vaccinated at school, but after a dog bit her, she went to the hospital to be vaccinated against rabies and when she had that vaccine, the doctors also vaccinated her against tetanus. Another participant (S8) had a misconception that vaccines may have beneficial bacteria.

Overloading Children with Vaccines (C3). One participant (S8) claimed that the children are overloaded with multiple vaccines while another one (S1) opposed that claim. He argued that the children's bodies produce approximately 6000 antibodies, so they can take even dozens of vaccines. At that point, another participant (S4) asked the following question: "What if a child has a disease or allergy against that vaccine? Can you still claim that this child can take 60 vaccines per week? I think this kind of child cannot take that much vaccine." The other one (S1) answered: "The doctors conduct allergy tests before vaccinating people. If people have allergies to a kind of medicine, the doctors don't give it to us." S4 said that he had nothing to say against this argument, but he was not convinced and insisted on his own claim. Another student (S9) from the audience participated in this discussion and opposed the claim that the children do not take 60 vaccines per week, and that children are instead vaccinated once per month or two months. The others disagreed with that claim too.

The Claims That Vaccines Are Unnecessary (C4 and C5). The participants opposed this claim by arguing that vaccines have a shelf life and that we need to be vaccinated again in the future. S1 claimed that the mortality rate in children was much higher before vaccinations. After the invention of vaccines, this rate decreased. S4 opposed that view by proposing the advancement in technology that he suggested earlier. He gave the example of using devices in some organs when necessary and claimed that the usage of these devices may decrease the necessity of vaccines. Another participant (S2) claimed that the MMR vaccine is the most dangerous one for children, but he did not provide any evidence for his claim. Other participants disagreed with these claims. After listening to others' views, S2 changed his mind.

The Claim That Vaccines Are No Longer Necessary (C6). S4 argued that if we are not vaccinated, we can be sick again. Others agreed with him, but S1 elaborated on this issue by arguing that even though diseases like polio have been eradicated in our country, a

person coming from abroad can cause these diseases to spread over the country again, so we need to keep being vaccinated.

The Claim That Vaccines Contain High Doses of Toxins That Can Harm People (C7). S2 argued that vaccines protect people from rabies, so they cannot include toxins. Most of the participants gave this example several times. Others claimed that the vaccines, that contain toxins, would be removed. S1 made a deeper reasoning that viruses are attenuated microorganisms that are introduced to the body in order to let it produce antibodies and fight against these viruses. He also emphasized keeping these viruses alive, so thimerosal or other substances are needed to keep them alive.

The Claim That Vaccines Are a Western Conspiracy (C8). All the participants argued that Western countries use these vaccines in their own countries. If vaccines were harmful, they would not use them on their own citizens. S1 argued that when ebolavirus flourished in a country, the WHO volunteered to help without any profit.

The Respecting Parents' Choices' Claim (C9). S3 gave the same example of a dog bite leading to rabies. S4 claimed that other children can be infected if one child is not vaccinated and becomes sick. Others supported him, but S6 opposed that view by defending parents' right to bring up their children according to the values and beliefs that they want. S6 also added that parents have a responsibility to keep their children healthy. S2 pointed to a similar issue by arguing that children can die in pain if they are not vaccinated. S1 also emphasized that there is scientific evidence that supports the benefits of vaccines.

In this discussion, other students respected S1's opinions and if they were not completely confident of their view, they could not insist on defending unscientific views. The status of the representative students' decision on whether they agreed with each claim is presented in Table 2.

In summary, in the plenary discussion, the groups discussed each of the claims presented to them in detail and expressed their thoughts. The representatives were either proponents or opponents of vaccines. However, they seemed to tend to change their minds if one of them was dominant and had the ability to convince others. In this plenary discussion S1 was the dominant student who had self-confidence of his knowledge about the topic. Others did not seem to have as much self-confidence as he had. They also positioned themselves in favor of or against vaccination and did not hesitate to express their own opinions. However, they rarely provided strong evidence for the claims they supported when they were asked to. On the contrary, S1 was always willing to give further evidence to support or refute a claim by giving various examples. In such cases, others changed their minds when their opinions conflicted with S1's explanations.

The findings revealed that the students made their judgments based on their peers' comments as well as their scientific knowledge. If they did not have enough knowledge about the topic and could not provide evidence for their false claims, they easily gave up their ideas. This result indicates that their reasoning depends on the evaluation of their peers who have scientific knowledge about the topic as well as other sources that provide scientific knowledge.

4.2 Results of Individual Interviews

Although S1 seemed to have convinced others through their scientific views, the researchers were still curious about the permanency of other students' thoughts. They also wondered whether they answered the same way or differently because of being alone in their explanations rather than the pressure of their peers. The interviewer was the second author

Table 2 The agreement status of the representative students in claims

Claim	Agreement	Disagreement
	n	*n*
Vaccines may cause autism	4	4
Vaccines cannot protect people against epidemic diseases	1	7
Children's immune system can be overloaded if the child receives multiple vaccines at once	1	7
Diseases have already begun to disappear before vaccines are introduced	2	6
The majority of people who get disease have been vaccinated	1	7
Since diseases like polio have disappeared from our country, it's no longer necessary to vaccinate children against them	-	8
Vaccines contain high doses of toxins that can harm humans	3	5
Vaccine is a Western conspiracy	-	8
We have to respect parents' choice not to vaccinate their children	1	7

of this paper. The researchers selected eight students, six of whom participated in this discussion (S1, S2, S4, S6, S7 and S8). The researchers selected these students to interview because S1 gave the most scientific explanation compared to his peers, S2 held unscientific beliefs, S4 linked protective function of vaccines to technology, S6 refused to be vaccinated at the school, however, got vaccinated after a dog bit her. S7 and S8 were also selected because they both have an autistic sister, and S3 and S5 were selected because they participated in the discussion when the representatives were explaining their groups' decision. The interviewees' responses to each of the claim are presented below:

Autism Claim (C1). Although S2 claimed that vaccines cause autism during the discussion, he then proposed an opposite claim that vaccines do not cause autism, rather they prevent it. When the interviewer asked why he changed his opinion, he mentioned the texts including the photos of sick people before vaccination was produced and the number of people that were healed after vaccination. He had a misconception that autism and albinism are epidemic diseases and can be treated by vaccines. During the interview, S4 made an interesting comment that some of the vaccines may cause autism, some may not. When the interviewer asked him which vaccines may cause autism, he answered that those that involve some additives; however, he couldn't mention any of them. He was also confused about the functions of vaccines. He claimed that some vaccines protect people against some diseases such as tetanus, mumps, rabies and autism, while others cause autism. During the plenary discussion, S7 said that she began to think about the relationship between autism and vaccines after reading the texts about it. During the interview, she agreed with this claim, but she also confessed that she had no evidence to support it. It is interesting to note again that although she thought that vaccines may cause autism, she also opposed the claim that vaccines include high doses of toxins that can harm people. S8 said that vaccines may cause autism during the plenary discussion. However, during the interview she changed her mind and explained that there is no relationship between vaccination and autism. She questioned this claim as follows: "If we didn't become autistic after vaccination, how did my sister become autistic? It seems like nonsense. So, I don't believe this claim, but as a matter of fact, I don't have enough knowledge about it." Others did not agree that vaccines cause autism. S6 referred to information from the internet that although scientists have decreased the amount of mercury in the vaccines, the rate of autism has not reduced. S10 explained that autism is a genetic disorder caused by mutations in the genetic code and therefore vaccines cannot cause this disorder. He defined mutation as the incorrect sequence of nucleotides in DNA. The interviewer asked him how he knew this information and he replied that in addition to learning this from his teacher and texts he read in class, he searched it on the internet.

Unprotection of Vaccines Claim (C2). S1 made the following explanation about the function of vaccines at the beginning of the interview: "The microorganisms that cause the disease are attenuated and these attenuated microorganisms are given to the body. They must be attenuated but alive. Then our body produces something to fight with them… Something, uhm… antibody, yes antibody. The body fights and learns to survive in this way." He said that he had obtained this information from documentaries and articles that he read on the internet. S4 thought that some vaccines offered protection for a limited period, while others were lifelong. S6 argued that vaccines protect people for a while. She could not list any other diseases except for influenza against which vaccines protect people. S7 was one of the few students who correctly defined the terms claim and evidence. Although she thought that vaccines may cause autism, she also believed that vaccines protect people from epidemic diseases and either reduce the incidence of some diseases or lead to their eradication. S8 could not explain the functions of vaccines, but she listed some

of the diseases such as influenza, measles and polio from which vaccines protect people. S9 repeated his argument that viruses become dormant for an aeon, but under certain conditions they can reproduce and infect people. He also mentioned mutation to explain why people become sick despite the vaccines. He said that when viruses mutate existing vaccines could not protect us anymore. S10 explained that vaccines protect people from epidemic diseases such as measles and the plague.

Overloading Children with Vaccines (C3). All of the interviewees disagreed with this claim as in the following quotation of S1: "Children produce 6000 antibodies, and a vaccine includes 100–200 antibodies. It was written in the readings. This amount is not enough to say that children are vaccinated too much." S1 seemed to be confused about antigen and antibody or just misspelled the term, antigen. Contrary to his previous explanations, S4 opposed this claim because S1 convinced him by providing scientific evidence. He said that even if he did not understand what S1 said, S1 seemed to have searched too many sources and was well-informed about the topic, thus he was convinced that children need to be vaccinated. S10 argued that the children are not vaccinated too much, since the amount of vaccines are predetermined scientifically; however, the people who claim the opposite are not aware of this scientific fact because they do not search enough.

The Claims That Vaccines Are Unnecessary (C4 and C5). The interviewees opposed this claim too. S1 gave the example of the plague from history as follows: "The black death first emerged in the 1200 s, in the Medieval Age, then stopped. In the 1600 s, during the Modern Age, (The Renaissance), it showed up again. Or rabies… If someone gets rabies, and if he/she is vaccinated they can be healed. Then if some time passes, he/she can get rabies again." When the interviewer asked where he got the information that the vaccines do not offer a person life-long protection, he explained that he did not read it anywhere, it was just his opinion. S10 argued that some epidemic diseases were eradicated with the help of vaccination, and we cannot stop vaccination because some microorganisms become dormant for thousands of years and can be activated unless we continue vaccination.

The Claim That Vaccines Are No Longer Necessary (C6). The interviewees opposed this claim. However, some of them had misconceptions about diseases. For example, S2 held the misconception that polio had been eradicated, so we do not need to vaccinate children against polio. The interviewer asked S4 what he meant by mentioning technology during the discussion. He replied that doctors treat people who have polio with an iron lung unless they are vaccinated.

The Claim That Vaccines Contain High Doses of Toxins That Can Harm People (C7). All of the interviewees disagreed with the claim that vaccines contain *high doses of toxins that can harm people*. S1 said that thimerosal is included in vaccines, but it is not toxic for people. It is interesting to note that S4 did not agree with the opinion that vaccines include high doses of toxins either despite his previous explanations about harmful additives that may be included in vaccines.

The Claim That Vaccines Are a Western Conspiracy (C8). The interviewees except S8 disagreed with this claim. S1 said that the conspiracy theory about vaccines may have originated from Western countries' exploitation of African and Middle Eastern countries for years. S2 made an interesting comment as follows: "Previously I thought that Western people want to decrease the Muslim population through poisonous vaccines, but I don't think the same way now. The teacher showed us some photos… The people who suffered from epidemic diseases before vaccines… People died in pain. Now, the number of people who become sick because of epidemic diseases has decreased. It was written in the uhm… in the texts that our teacher distributed to us." Only S8 believed this conspiracy theory. Interestingly, she claimed that developed countries may have been adding harmful substances to

vaccines to kill some people in underdeveloped countries. However, she could not justify her opinion when the interviewer asked her to do so. When the interviewer asked why they would do such a thing and where she got that information, she replied that the developed countries wish to overcome the overpopulation throughout the world, and she heard S1 say that. In fact, S1 never said that. S9 made the following explanation: "These are conspiracy theories, gossip… Uhm… In western countries people gossip about vaccines without evidence and spread this gossip throughout the world. The people in our country import all these ideas from the West." Interestingly, S10 applied another conspiracy theory to criticize conspiracy theories as follows: "The ignorant people or conspiracy theorists spread their ideas to avoid the development of other nations."

The Respecting Parents' Choices' Claim (C9). All the interviewees opposed this claim by arguing that vaccines are not only necessary for their children's health but also public health. S6 was the only student who defended that we must respect parents' choice not to vaccinate their children during the discussion, but she said that she changed her mind after the discussion because her friends convinced her about the transmission of disease from unvaccinated to vaccinated people. However, it is interesting to note that she still thought that parents can do anything they want to their children, even beating them or administering similar harm. Table 3 summarizes the students' agreement with the claims during the individual interviews.

It is noteworthy to emphasize some critical points that emerged from interviewees' explanations. Since three interviewees (S4, S7 and S8) cited S1's explanations, it can be inferred that the hard-working and well-informed students may influence their peers. It is also interesting to note that none of the students listed more than three epidemic diseases that were reduced or eradicated throughout history.

5 Conclusions and Implications

It is especially important in today's pandemic, during which science denial and the anti-vaccine movement have been spreading throughout Turkey and the world, to promote students' scientific literacy and their decision-making skills about socio-scientific issues. Science education plays an important role in this sense because it provides the solutions required to combat science denial and post-truth (Valladares, 2021). In today's society, individuals are expected to make decisions and make rational actions over a range of individual and social issues (Song et al., 2021). As Hodson (2021) suggested, it is crucial, thus, to increase their ability to access scientific knowledge, develop media literacy and political awareness as well as an ethical understanding of issues for a critical evaluation of these issues. From this perspective, it is necessary to examine middle school students' reasoning to design instructions enhancing students' scientific knowledge and argumentation based on evidence.

Since students have difficulty evaluating both scientific claims and web-based claims, there is a need for instructional intervention initiatives to help students' reasoning (Tseng et al., 2021). The present study investigated eighth graders' reasoning about vaccination in a context of a four-week implementation that included a five-phased instruction during science lessons. Representative students' explanations during plenary discussion revealed their lack of knowledge about vaccines. However, the interviewees' responses showed that students seemed to be aware of false claims and conspiracy theories about vaccination. This difference might have arisen from the students' change in their minds or the

Table 3 The individual students' agreement with the claims

Claim	Agreement	Disagreement
	n	*n*
Vaccines may cause autism	1	7
Vaccines cannot protect people against epidemic diseases	-	8
Children's immune system can be overloaded if the child receives multiple vaccines at once	-	8
Diseases have already begun to disappear before vaccines are introduced	-	8
The majority of people who get disease have been vaccinated	-	8
Since diseases like polio have disappeared from our country, it's no longer necessary to vaccinate children against them	-	8
Vaccines contain high doses of toxins that can harm humans	-	8
Vaccines are a Western conspiracy	1	7
We have to respect parents' choice not to vaccinate their children	-	100

requirements of plenary discussion and interviews. One possible interpretation of this difference can be that students learned from the discussions with peers as well as the scientific knowledge that the teacher introduced. On the other hand, this difference may also be interpreted as the representatives' responsibility to reflect on group judgment, while each one of them were free to reflect on their own thoughts during the interview. Further investigation of students' reasoning both individually and in groups before and after such an instruction may clarify this issue. However, the findings of the plenary discussion are noteworthy as they indicate peer influence on students' reasoning.

As suggested by Arede et al. (2019), the importance of targeting children and adolescents who might not have strong feelings about vaccines was also revealed in this present study. The results of the current study stated that students who lack knowledge about vaccination tend to accept scientific knowledge when they encounter *sufficient* scientific knowledge on this subject. In addition, the results of the present research reveal that discussing false claims about vaccination in the classroom can help students to deal with the uncertainty inherent in scientific knowledge.

During the plenary discussion, students who were unable to argue the false claims based on evidence relied on the explanations of their peers who made judgments by referring to scientific knowledge and stated that they were convinced. They did not insist on defending false claims if they were provided with strong arguments based on evidence even if their group concluded the opposite. This finding indicates that students' reasoning tends to be influenced by their peers unless they have scientific knowledge about the topic. Similarly, Norris and Phillips (1994) stated that the students who read the popular reports of science accepted the claims of the reports without questioning the evidence or information even though no more than half of the students did not accurately understand the role of the statements in these reports. This result suggests the need to increase students' scientific knowledge and reasoning to promote their reasoning and make judgments based on evidence.

During interviews, three students' explanations referred to their peer, who was the most knowledgeable about the topic. This result indicates the necessity of not only promoting students' scientific knowledge, but also facilitating peer discussion about fallacies, conspiracy theories, and false claims about socio-scientific topics in the classroom. Curriculum makers and science educators should consider this necessity during their designs. When considering scientific knowledge and scientific evidence, it is thought that discussion of these topics with peers, as well as the teacher, is necessary to support the elimination of misinformation. As such, it is important that these topics are incorporated into all science classes.

According to Höttecke and Allchin (2020), culture is changing dramatically, and science education needs to adapt to this change. The present study employed a teaching method including students' reading and discussing texts of false claims and conspiracy theories during 5-weeks of instruction and in this context, explored students' reasoning about vaccines during a plenary discussion and individual interviews. This study can be considered as an attempt to adapt to this change by suggesting that in addition to scientific knowledge, discussions of fallacies and conspiracy theories should be included in science classes to cope with the uncertainty in science. Further studies investigating the effectiveness of methods to increase students' knowledge and reasoning about vaccines seem necessary.

The current study explored students' reasoning in a five-phased instruction of science lessons by probing deep into their analysis of each claim. From this aspect, this study is one of the initial attempts on middle students' thoughts and reasoning on vaccines and it is promising to inspire further instructional designs and research on students' reasoning. However, it shows only what students may gain after such an implementation.

Investigating the students' reasoning before and after this intervention was not the scope of this study. This is the biggest limitation of this study. Overcoming this limitation, such an exploration may bring new insight to this issue. Such an investigation may broaden our perspective in terms of designing science curriculum that especially considers socio-scientific issues.

Zeidler et al. (2019) emphasized the need to shift a student's own perspective to that of another in order to understand how this perspective occurs, which also facilitates the integration of habits of mind. They argued that displaying open-mindedness, respecting others' arguments and employing sociocultural normative features promotes moral judgment. The current study is an attempt to fulfill this requirement in the pursuit of educating citizens who acquire democratic and scientific decision-making skills by revealing the students' reasoning about vaccination. Further studies examining moral judgments and affective factors in an argumentative discourse environment to facilitate informed decision-making may bring new light to this issue.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11191-021-00318-8.

Acknowledgements Special thanks are given to the anonymous reviewers who helped to improve this paper with their critical comments and suggestions. The authors also would like to appreciate to Sezer Yazar for his proofreading efforts.

Declarations

Conflict of Interest The authors declare no competing interests.

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