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Teaching socio-scientific issues through evidence-based thinking practices: Appropriateness, benefits, and challenges of using an instructional scaffold

Sosyo-bilimsel konuların kanıta dayalı düşünme uygulamaları ile öğretilmesi: Öğretim iskelesi kullanmanın uygunluğu, yararları ve zorlukları

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Abstract. Teachers are expected to improve their students' analytical thinking and decision-making skills through evidence-based thinking and critical evaluation processes. In this study, a three-hour workshop was conducted to investigate science teachers' views about teaching socio-scientific issues through argumentation and introducing an instructional scaffold, Model-Evidence Link diagrams to promote the use of argumentation and critical evaluation in science classrooms. 125 science teachers, who were working in public schools of an urban area in Turkey participated in the workshop. Findings revealed that 90% of the participants stated that the use of MEL diagram is appropriate for science teaching. Promoting higher order thinking skills was the highest benefit, whereas the need for time for the development and implementation of the material was the greatest challenge for the use of the MEL diagrams in science classrooms. This study contributes to the literature on teaching socio-scientific issues, especially through argumentation, evidence-based thinking, and critical evaluation.

Keywords: Evidence-based thinking, argumentation, socio-scientific issues, climate change

Öz. Öğretmenlerin kanıta dayalı düşünme ve eleştirel değerlendirme süreçleriyle öğrencilerinin analitik düşünme ve karar verme becerilerini geliştirmeleri beklenmektedir. Bu çalışmada, fen öğretmenlerinin sosyo-bilimsel konuların tartışma yoluyla öğretilmesini ve fen derslerinde argümantasyon ve eleştirel değerlendirmenin kullanılmasını teşvik etmek için bir öğretim iskelesi, Model-Kanıt Ilişki (MKI) diyagramları'nın kullanılması konusundaki görüşlerini araştırmak için üç saatlik bir çalıştay yapılmştır. Çalıştaya, Türkiye'de bir kentsel bölgenin devlet okullarında çalışan 125 fen bilgisi öğretmeni katılmıştır. Bulgulara göre, katılımcıların % 90'ı MKI diyagramının fen bilgisi öğretimi için uygun olduğunu belirtmiştir. Katılımcılara göre, MKI diyagramının fen derslerinde kullanılmasının en büyük faydası öğrencilerin üst düzey düşünme becerilerini geliştirmesi, materyali geliştirmek ve uygulamak için zamana ihtiyaç duymak ise en büyük zorluk oldu. Bu çalışma, tartışma, kanıta dayalı düşünme ve eleştirel değerlendirme yoluyla sosyo-bilimsel konuların öğretilmesine ilişkin literatüre katkıda bulunmaktadır.

Anahtar Sözcükler: Kanıta dayalı düşünme, tartışma, sosyobilimsel konular, iklim değişikliği

This study has been presented at the 2017 Northeast Association for Science Teacher Education (NE-ASTE) Regional Conference in Burlington, VT, USA.

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INTRODUCTION

One of the main goals of science education is to develop scientific literacy and improve the understanding of scientific practices. Argumentation, critical evaluation, and evidence-based thinking are important elements of scientific practices (Mugaloglu, Can, & Ceyhan, 2017). Argumentation mainly refers to constructing an argument, which consists of pieces of evidence and a claim (Simon, Erduran, & Osborne, 2006). The term critical evaluation refers to evaluating evidence and argument to make a decision. Both argumentation and critical evaluation require evidence-based thinking. In a nutshell, to fulfill the aim of scientific literacy in general and understanding scientific practices in particular, students need to develop argumentation; critical evaluation and evidence-based thinking skills. Moreover, argumentation and critical evaluation are recommended as an effective method in teaching science (Ministry of National Education in Turkey, MONE 2013, 2017). During teaching practices, teachers guide their students to construct an argument and make a critical evaluation based on arguments and shreds of evidence. Experiencing argumentation, critical evaluation and evidence-based thinking can also contribute to understand nature of science and to appreciate the scientific knowledge. Especially while teaching socio-scientific issues such as global warming or genetically modified organisms, evidence-based thinking is vital in students' attainment and taking decisions as an informed citizen. These issues are complicated since they contain various aspects such a social, political, economic.

Teachers have difficulties in teaching socio-scientific issues because the related arguments and evidence may have social controversies. This study focuses on science teachers' views about the challenges and the difficulties that come with teaching socio-scientific issues, specifically global climate change. It also explores the teachers' views about teaching global climate change with evidence-based thinking approach. Moreover, one of the difficulties in teaching socio-scientific issues through argumentation is a limited source of teaching materials (Kara, 2012). Therefore, the present study also investigates the benefits and the challenges of using an instructional scaffold, which aims at promoting scientific thinking and critical evaluation of the relationship between data and model considering alternative explanations of the issue at hand (Lombardi, Sinatra, & Nussbaum 2013). This study contributes to the literature on teaching socio-scientific issues, especially through argumentation, evidence-based thinking and critical evaluation. Besides, the investigation of the science teachers' views of teaching socio-scientific issues by using the instructional scaffold, Model-Evidence Link (MEL) Diagram, contributes to science teacher education literature. With this goal, the purpose of this study is to investigate science teachers' views about teaching socio-scientific issues through evidence-based thinking practices. The research questions are:

What are science teachers' views about

- the appropriateness of using MEL diagram in science classrooms?
- the benefits of using MEL diagram?
- the challenges of using MEL diagram?

LITERATURE REVIEW

Critical evaluation in scientific reasoning has been studied in many fields such as developmental psychology, educational psychology, and science education research. According to Kuhn (1999), critical evaluations are judgments about the quality of explanations based on "criteria of argument and evidence" (p. 23). Central to our theoretical framework is the idea that evaluations about knowledge and how knowledge is constructed involves judgments from scientific reasoning, acquisition of scientific knowledge and scientific practices.

Since the early 1990s, science education reform efforts have focused on the notion that science teaching should be consistent with the nature of scientific inquiry (MONE, 2004). The National Research Council (NRC, 2015) has recently promoted this idea, saying that science teachers should express "knowledge, skill, and competencies associated with scientific practices, disciplinary core ideas, and crosscutting concepts; and the pedagogical content knowledge and teaching practices that support students in rigorous and consequential learning of science" (p. 95). In response to the need of promoting scientific practices in science classrooms, Erduran and Dagher (2014) developed the Benzene Ring Heuristic to define the dynamic nature of epistemic, cognitive, social components of scientific practices, which are the real world, prediction, explanation, model, data and activities. All of these components are related to each other and include social practices of science such as argumentation and social certification.

Saribas and Ceyhan (2015) introduced BRH to pre-service science teachers in order to investigate their perceptions of scientific processes and improve their understanding of science and scientific practices. Findings of their study revealed that in order to increase understanding of the scientific practices, science teachers should deepen understanding about the nature of science, including the idea that "scientific explanations are based on logical and conceptual connections with evidence validated through evaluative processes" (the NGSS Lead States, 2013, p. 98). Therefore, providing explicit and purposeful professional development to science teachers about designing lessons on evidence-based scientific explanations is one crucial component needed to increase the likelihood that science teachers will effectively engage their students in critical evaluation and evidence-based explanations (Mugaloglu et al., 2017; Saribas, Ceyhan, & Lombardi, 2019).

Our perspective on critical evaluation draws upon evidence-based thinking and application of scientific practices. The Model-Evidence Link (MEL) Diagrams used in this study are instructional scaffolds that focus on the connections between the components of scientific practices through evidence-based explanations. Specifically, MEL Diagrams aimed at promoting critical evaluation through making connections between pieces of evidence and alternative explanations (Lombardi et al., 2013). Chinn and Buckland (2012) first designed the original version of the MEL diagram in order to use in middle school science lessons. Lombardi and his colleagues (2013) developed a MEL diagram for climate change to investigate students' ability to critically evaluate arguments and develop their understandings of fundamental concepts about climate change. The results of their study showed that use of MEL diagram increased students' knowledge about fundamental scientific principles related to climate change that was sustained six months after instruction (Lombardi et al., 2013). Lombardi and his colleagues (2013) suggest that teachers can use MEL diagrams to help students evaluate evidence and explanations by promoting collaborative scientific argumentation.

Using argumentation as well as scientific evidence has long been considered to be beneficial in teaching and learning science. Teachers' use of argumentation as an instructional strategy as well as students' argumentation skills develop over time and with professional development (Osborne, Erduran, & Simon, 2004). If teachers are to engage students in argumentation that promotes coordination and critical evaluation of scientific evidence and explanations, we assume they should experience similar activities with professional development based upon our understanding of the literature on the scientific practices, critical evaluation, and scientific argumentation. In the present study, we investigated how a professional development program on evidence-based thinking practices shaped the teachers' views about the benefits and challenges of teaching socio-scientific issues, specifically climate change.

METHOD

Participants

In order to investigate science teachers' views about teaching socio-scientific issues through argumentation, a three-hour workshop was conducted with 125 science teachers, who were working at public schools of an urban area in Turkey. Specifically, the study was conducted in Kocaeli as a teacher professional development training for science teachers working in public schools. Teachers were informed about the workshop through Kocaeli Directorate of National Education and volunteered teachers participated in the study. Participants were predominantly female (76%), and their teaching experiences were presented in Table 1.

Table 1. *Participants' teaching experiences*

Teaching experience	*N*	%
1 – 5 years	40	32
6 – 10 years	40	32
11 and above years	37	30
Not indicated	8	6
Total	125	100

Procedure

Participants were randomly divided into four groups, and in each group, there were approximately 31 participants. A three-hour workshop was conducted with each group. At the end of the workshop, participants were asked to fill a feedback form. The design of the workshop was scaffolded in an interactive lecture, group activity, and discussion (see Figure 1).

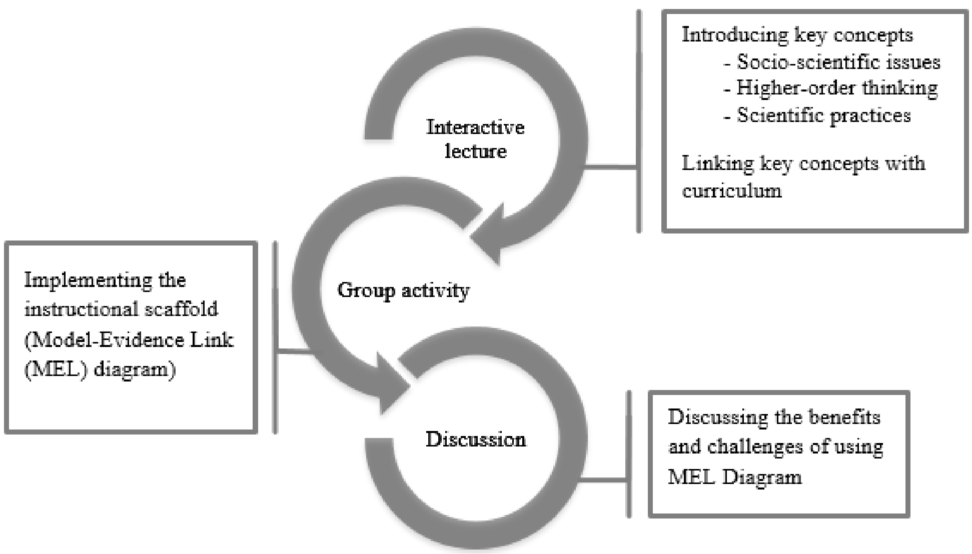

FIGURE 1. *The schema for the design of the workshop*

The interactive lecture part of the workshop started with an online activity that asked participants to fill the sentences that starts with "science education is ….." and "….. should be developed in science education". The online program lets the participants share their results immediately and anonymously. Therefore, participants had a chance to discuss the answers given. Then, the participants were introduced with the goal, mission, and vision of Turkish science education curriculum (MONE, 2013) regarding scientific skills and scientific practices. The participants were also asked to determine the key terms in the statement given below:

"Scientifically literate individuals have the basic information related to science and have the necessary scientific process skills. These individuals can make alternative explanations and produce solutions by using creative and analytical thinking skills" (MONE, 2013, p.1).

Participants focused on the concepts regarding socio-scientific issues, as well as argumentation and critical evaluation that takes place in the National Science Curriculum in Turkey. In order to present similarities of the goals of science curriculum in other countries, participants were introduced with the model showing science and engineering practices that take place in Next Generation Science Standards (NRC, 2012). After determining the key terms in the science curriculum, participants were asked to relate the scientific practices and the objectives of the National Science Curriculum in Turkey. With a brief discussion, participants collaboratively argued their positions on the challenges in teaching socio-scientific issues through argumentation; particularly climate change was presented as an issue for critical reflection.

In the group activity part of the workshop, the instructional scaffold was displayed to promote thinking skills and to facilitate understanding of scientific practices (details about the instructional scaffold will be provided in the next section). Firstly, participants were introduced with the material by providing a detailed explanation on the purpose and the procedures of the activity. Then, participants, in groups of three or four, actively engaged in the activity for an hour. The instructional scaffold is explained in detail in the materials section. In the discussion part of the workshop, participants discussed the benefits and challenges of teaching socio-scientific issues and using the instructional scaffold in the classroom. Participants also evaluated the instructional scaffold concerning its appropriateness to the curriculum and to the grade to teach climate change (as an example of socio-scientific issues) through argumentation.

Evidence-based teaching material: Global climate change MEL diagram

The instructional scaffold that was introduced and implemented in the workshop was the MEL diagram, which includes three parts; relating models with evidence, providing reasons for model-evidence relations (i.e., explanation task), and rating the plausibility of each model (see Figure 2). For the MEL activity that was used in the workshop, two models and four pieces of evidence were provided. The models presented two alternative explanations for the cause of the current climate change, which are "Model A" the scientifically accepted statement that humans are the main cause of the current climate change (Intergovernmental Panel on Climate Change (IPCC), 2013), and "Model B" the alternative statement that current climate change is caused by an increase in the Sun's energy (e.g. Pruneau, Gravel, Courque, & Langis, 2003). The MEL diagram also included four evidence statements about current climate change, which explained (1) the change in the greenhouse gas emissions throughout the years, (2) the current changes in the solar activity, (3) the observed influence of greenhouse gases on Earth's energy budget, and (4) the changes in the solar activity throughout the years. Each evidence statement in the MEL activity was supported with "evidence texts" each of which is one-page in length. The evidence texts included graphs, diagrams, and tables to detail the evidence statements.

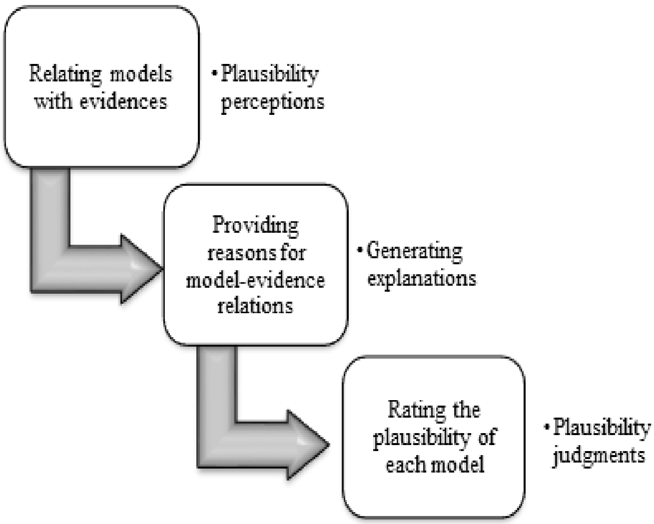

FIGURE 2. *The flow of the MEL activity*

In the first part of the MEL activity, participant groups were expected to relate each evidence with each model by drawing an arrow to show the relationship between the model and the evidence. Four types of arrows were provided in the MEL activity, which was (a) a straight line representing the evidence supports the model, (b) a squiggly line representing the evidence strongly supports the model, (c) a straight line with an "X" on it representing the evidence contradicts the model, (d) a dotted line representing the evidence has nothing to do with the model (see Figure 3).

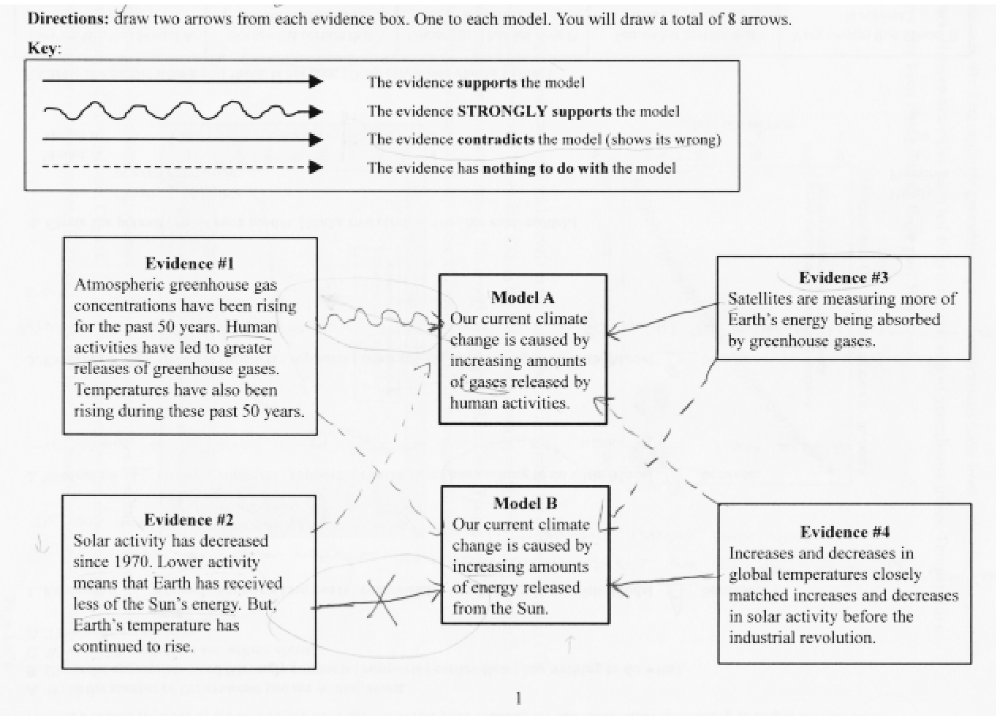

FIGURE 3. *An example of the MEL diagram*

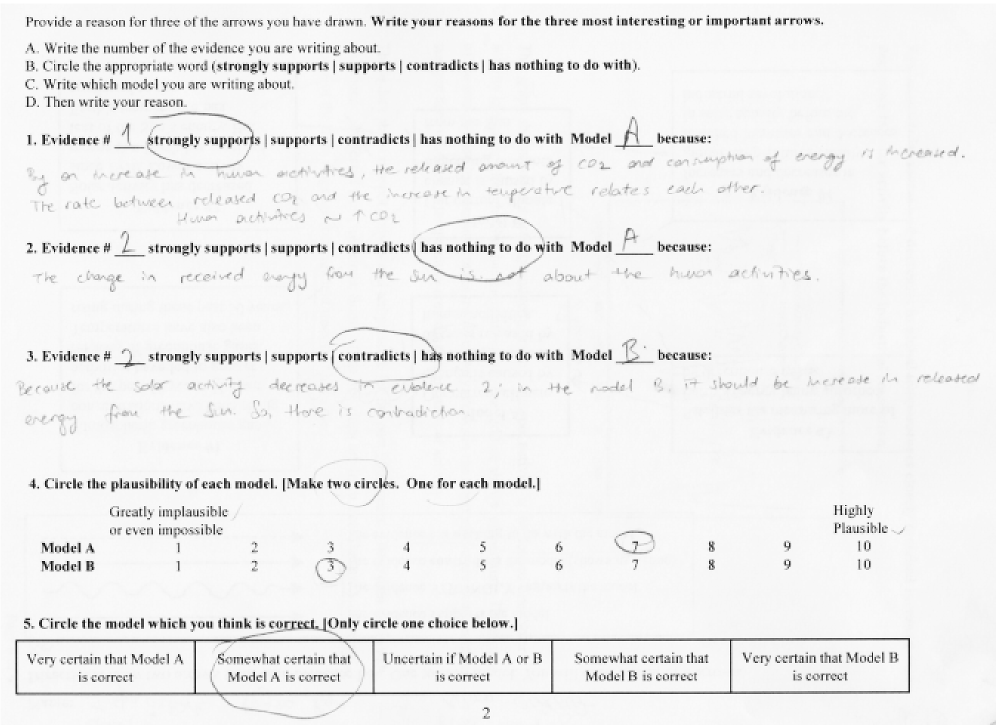

FIGURE 4. *An example of the explanatory tasks*

In the second part of the MEL activity, participant groups were expected to provide reasons for the model-evidence relationships that they made in the first part. This part is also referred to as explanation task. Participants were asked to determine the three most interesting or important relationships and explain the reason for this relationship in their own words by referencing to the evidence texts. For instance, one of the participant groups' explanation was "Evidence #2 has nothing to do with Model A because the change in received energy from the Sun is not about the human activities." Finally, in the last part of the MEL activity, participant groups rated the plausibility of each model by using a 1-10 scale (1 = greatly implausible, 10 = highly plausible) in order to reveal their plausibility judgments of the cause of current climate change (see Figure 4).

Data Collection tool and materials

After the implementation of global climate change MEL diagram, participants were asked to fill the feedback form which was used as a data source in this study. The feedback form includes four open-ended questions and demographic questions such as teachers' years of experience. The authors of the current study, who are science education researchers, developed the feedback form to respond the research questions. Open-ended questions in the feedback form were as follows:

- Is it appropriate to use the MEL activity in science classrooms?
- For which grades can we use the MEL activity?
- What are the benefits of using the MEL activity in science classrooms?
- What are the challenges and difficulties of using the MEL activity in science classrooms?

We started to analyze data by reading, rereading and coding to determine the views of the participants about the benefits and challenges of using the MEL activity in science classrooms. Specifically, we used a constant comparative method in the data analysis to examine similarities and differences between the previous and new findings (Glaser, 1965). Data coding started with dividing each participant's responses to each research question into meaningful units in order to reduce data for analysis. Throughout data analysis, seven codes for the benefits of using the MEL activity in science classrooms and five codes for the challenges and difficulties of using the MEL activity in science classrooms were identified (see Table 2). The results will be presented in terms of these codes.

Table 2. *The codes for the benefits and challenges of using MEL diagram*

Research questions	Codes
What are the benefits of using MEL activity in science classrooms	Promote higher order thinking
	Promote analytical thinking
	Promote the use of science process skills
	Promote critical thinking
	Promote creative thinking
	Help overcome misconceptions
	Help discussing socio-scientific issues
What are the challenges of using MEL activity in science classrooms	Need for time
	Not appropriate for all grades
	Not appropriate for all topics
	Not appropriate for crowded classrooms
	Need for material / Hard to prepare the material

RESULTS

The results are presented in three sections, each addressing one research question. The first section presents participants' views about the appropriateness of using MEL diagrams in the science curriculum, the second section reveals participants' views about the benefits of using MEL diagrams, and the third section shows participants' views about the challenges of using MEL diagram.

Participants' views about the appropriateness of using MEL diagrams in science classrooms

Although participants stated some of the challenges of using MEL diagrams in science classrooms, the vast majority of them (90%), regardless of a significant difference on teaching experience, stated the appropriateness of its use in classrooms. To quote a participant, "with this activity, students at any grade level can have a chance to use scientific evidence to support their claims." Another participant stated, "The use of this activity at various grade levels and various topics, such as socio-scientific issues would help students consider alternative explanations." However, a few participants complained about the appropriateness of MEL diagram in the science curriculum in Turkey, and one of them stated that "normally yes, but not in our educational system," and another participant stated that "technically good, but hard to implement because it requires higher-order thinking."

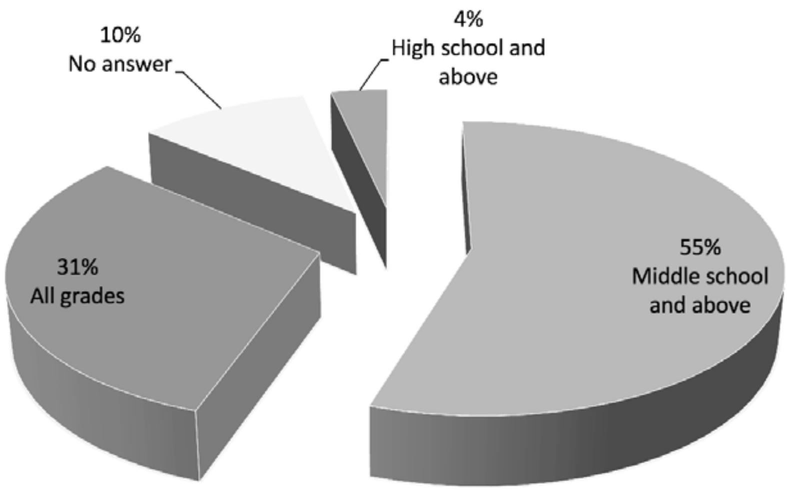

FIGURE 5. *Participants' views on which grades we can use the MEL activity*

As seen in Figure 5, slightly above half of the participants (55%) stated that it is appropriate to use MEL diagram at middle school and above, whereas 31% of the participants expressed that it can be used at any grade level, to quote a participant, "it can be used at every grade level by considering student learning." Another participant emphasized the importance of using MEL diagrams at early ages to improve higher-order thinking skills by stating, "If the child gets the ability to think critically at a young age, he/she can apply such skills more easily in daily life."

Participants' views about the benefits of using MEL diagram in science classrooms

Of the 125 participants, 59 (47 %) stated that using MEL diagrams in science classrooms promote higher order thinking (see Figure 5). One of the participants stated that "using this (MEL) activity in the classroom helps students improve higher order thinking skills and leads students to think deeply." Another participant said, "MEL activity promotes higher order thinking and helps students make critical evaluation." The teachers who have more than five years of experience stated promoting analytical thinking as the second highest benefit of using

MEL diagrams in science classrooms. Teachers with less experience (1 to 5 years) cited the use of science process skills as the second benefit of using MEL diagrams.

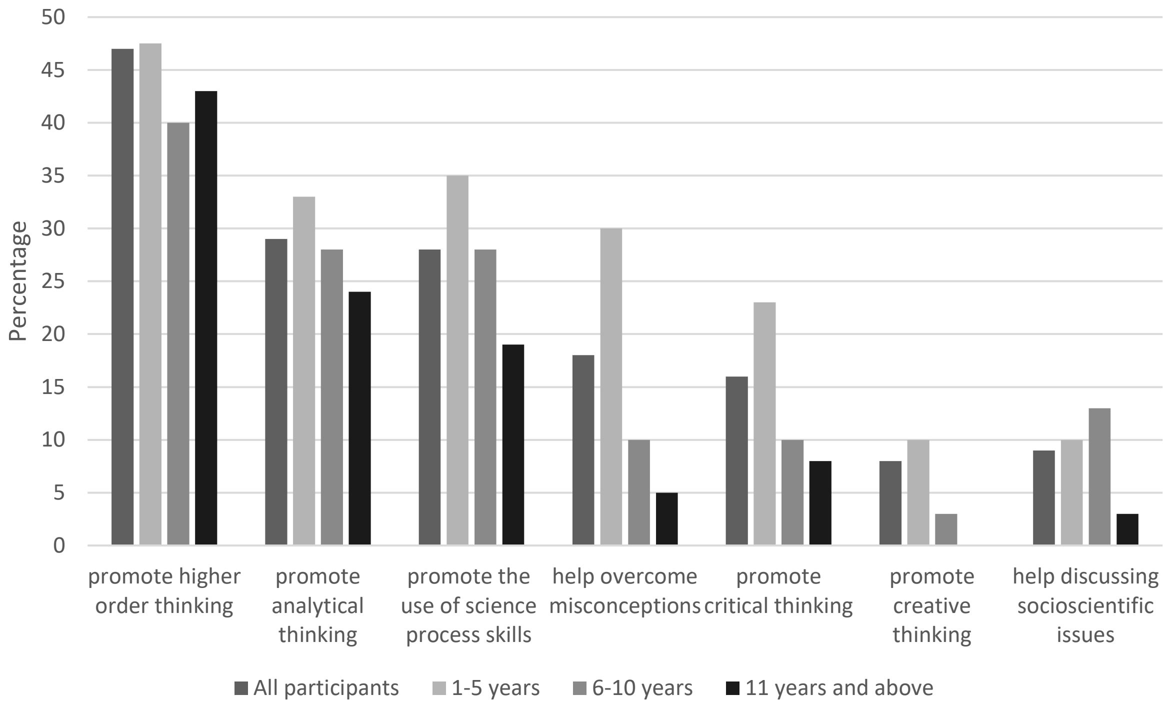

FIGURE 6. *Participants' views about the benefits of using MEL diagram*

As seen in Figure 6, there is a decreasing trend in most of the codes about the benefits of using MEL diagrams in science classrooms regarding teaching experience. In other words, teachers who have less than six years teaching experience usually mentioned the benefits of using MEL diagrams more than teachers who have teaching experience greater than five years. For instance, teachers with one to five years teaching experience mentioned the benefit of using MEL diagrams on helping overcome misconceptions and promoting critical thinking more than teachers who have experienced greater than five years. Moreover, even though other teachers talked about the benefits of promoting creative thinking, none of the teachers who have experienced more than eleven years mentioned the benefits of MEL diagrams in promoting creative thinking.

Participants' views about the challenges of using MEL diagram in science classrooms

As seen in Figure 7, almost half of the participants (42%) stated that the greatest challenge of using MEL diagram is the need for time. However, teachers who have six to ten years' experience were the least among other participants who talked about this challenge. One of the participants mentioned this challenge by stating, "It may be hard to do this activity because it will be much time consuming." One of the participants expressed the loaded science curriculum in Turkey as a limitation for the time needed of using MEL diagrams in her classes.

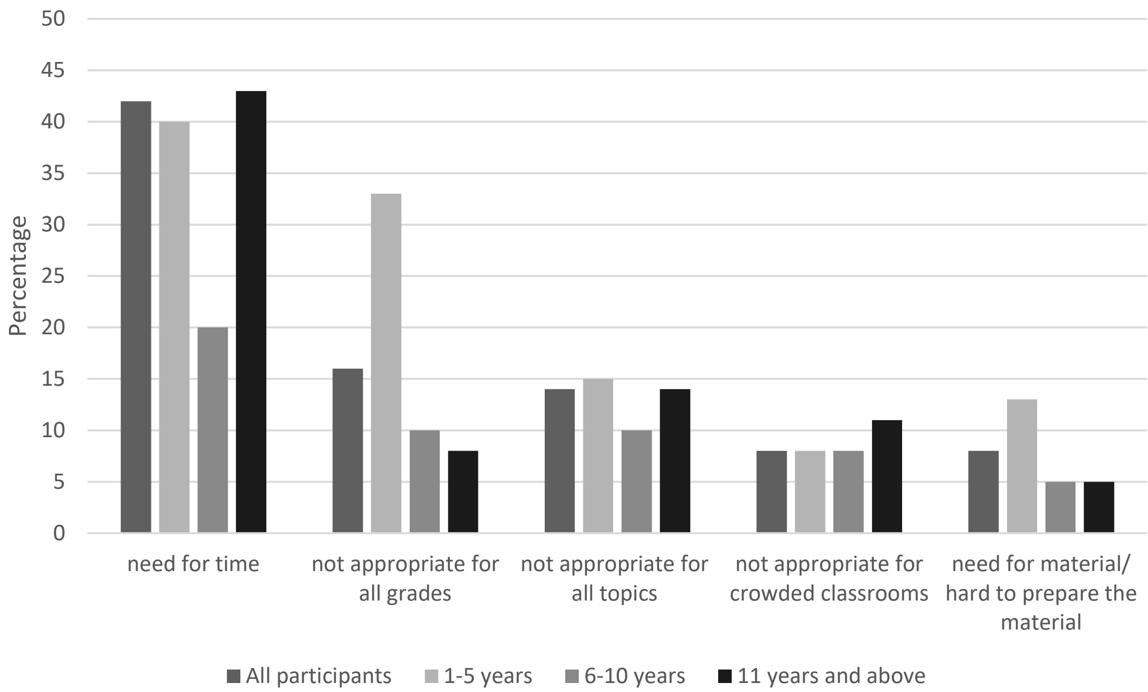

FIGURE 7. *Participants' views about the challenges of using MEL diagrams*

Another finding of the challenges of using MEL diagrams in science classrooms is that majority of the participants who stated that MEL diagrams are not appropriate for all grades are teachers with one to five years of teaching experience. One of the teachers with two years of teaching experience stated, "Students at smaller grades would have difficulty in comprehending the activity." Another teacher stated, "It may be challenging for students at low grades to work with scientific data and have a fruitful argumentation with the claims and evidence." Less than 15% of the participants mentioned that using MEL diagrams in science classrooms are not appropriate for all topics and crowded classrooms, and it is not easy to prepare the material. Teachers who would have been less than six years of teaching experience stated the need for support materials more than more experienced teachers.

DISCUSSION AND CONCLUSION

The primary aims of this study were investigating science teachers' views about the benefits and the challenges of using an instructional scaffold, the Model-Evidence Link (MEL) diagram, to promote scientific thinking and critical evaluation of the relationship between data and model, as well as the appropriateness of using MEL diagrams in science classrooms. Our findings reveal that the large majority of the participants stated the appropriateness of using MEL diagrams in science classrooms. Majority of the participants indicated that using MEL diagrams in science classrooms is more appropriate to use in middle school or above because the participants stated that it requires higher-order thinking, abstract, and analytical thinking skills, as well as reinforces critical evaluation. This finding aligns with the literature, where Lombardi and his colleagues (2013) originally designed the MEL activity for middle school students, then it was used with high school students (Lombardi et al., 2018) and with preservice teachers to examine their evaluation levels (Saribas & Akdemir, 2019; Saribas et al., 2019). Our findings add to the existing literature suggesting that teachers can use instructional scaffolds, such as MEL diagrams to promote students' evaluations of evidence and explanations by providing a collaborative scientific argumentation environment (Lombardi, et al., 2013). It was promising to see that science teachers were open to use new teaching materials while appreciating the benefits as well as considering the challenges of doing so.

The participants revealed the benefits and the challenges of using MEL diagrams in their classrooms. The most common response on the benefits of using MEL diagrams in science classrooms was promoting higher-order and analytical thinking skills, which are in line with the objectives of the Ministry of Education in Turkey (2013; 2017) as well as the current literature (Lombardi et al., 2018; Saribas & Akdemir, 2019). Students' plausibility judgments may be associated with scientific and critical thinking (Lombardi et al., 2018). As "students need tools to evaluate arguments" (Nussbaum & Edwards, 2011, p. 447), instructional tools like MEL diagrams can be useful to improve students' higher-order thinking skills and promote evidence-based explanations in science classrooms. The biggest challenge that the participants stated for the use of MEL diagrams in science classrooms were the need for time for development and the implications of using the materials considering the heavy curriculum and the preparation time for the national exams. The new curriculum with fewer objectives may be promising for teachers to include more classroom activities in their lesson plans (Öztürk, 2019). Moreover, following the objectives of the new national science curriculum, program developers and teachers should not only focus on improving the content knowledge of the students, but also on developing skills such as argumentation, critical evaluation, and promoting higher order thinking skills. We believe the knowledge base on the evaluation of the teacher professional development program helps us improve the instructional scaffold materials as well as increase the efficiency and the effectiveness of the use of them in classrooms.

Finally, the participants with different levels of teaching experience focused on different benefits and challenges of using MEL diagrams in science classrooms. Prior studies reported significant differences between instructional planning skills and decisions of novice and experienced teachers (Yildirim, 2003). Our findings revealed that teachers with one to five years teaching experience mentioned the benefit of using MEL diagrams on helping overcome misconceptions and promoting critical thinking more than teachers who have experienced greater than five years. The decreasing trend in the majority of the codes about the benefits of using MEL diagrams in science classrooms regarding teaching experience shows the importance of in-depth qualitative analysis to reveal the needs of teachers with different teaching experiences. Further studies may close this gap with individual interviews and focus group discussions with teachers who have similar years of experience to determine their needs and expectations from professional development programs.

During the workshop, the participants engaged with the activities by asking questions and actively participating in the discussions. In line with the literature, our findings suggest that effective teacher development can improve the use of collaborative argumentation techniques such as evaluating alternative explanations to construct scientifically accurate knowledge (Erduran, Ardac, & Yakmaci-Guzel, 2006). We believe defining and improving science teachers' evaluating connections between evidence and explanations is crucial to promote classroom engagement in scientific argumentative practice. The investigation of participants' views on the appropriateness, benefits and challenges of using an instructional scaffold provides an in-depth understanding of teaching socio-scientific issues through evidence-based thinking practices in the context of a middle school science teachers working in public schools in an urban area in Turkey during the time of this study. The findings will be limited to reflect the perspectives of this group of teachers' views on the use of MEL diagrams in this context. Therefore, this study may provide insight into similar teacher groups working in similar conditions, but the readers should be cautious when making interpretations to transfer the implications to other contexts (Creswell & Poth, 2018). Future studies may investigate the teachers' views about the use of MEL diagrams with different teachers working in public and private schools and with various socio-scientific issues that takes place in the curriculum. Also, further studies may explore teachers' and students' views after MEL diagrams have been used in science lessons.

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