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ORIGINAL RESEARCH

The Integration of a Lesson Study Model into Distance STEM Education during the COVID-19 Pandemic: Teachers' Views and Practice

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Abstract
This paper investigated the integration of a Lesson Study Model (LSM) into distance STEM education during the COVID-19 pandemic. The study focused on six dimensions: (1) STEM education in distance learning, (2) Lesson Study (LS), (3) lesson planning processes, (4) challenges of lesson planning, (5) evaluation and assessment methods, and (6) strategies, methods, and techniques. The sample consisted of 24 science teachers recruited using criterion sampling, which is a purposive sampling method. A case study, which is a qualitative research method, was the design of choice. Data were collected through interviews, videotapes, and expert observations. The data were analyzed using inductive content analysis. Themes, categories, and codes were developed in accordance with the research purpose. Participants had positive opinions about the LSM, STEM education, and distance learning. Participants stated that the LSM activities within distance learning contributed to pedagogy and content knowledge in the STEM education process. The challenges faced by participants were unfavorable environmental conditions, time management issues, and a lack of knowledge and experience in lesson planning. Expert observations and videotapes corroborate these results, indicating that the LSM integrated with STEM education results in higher quality STEM lesson planning and teaching. Moreover, distance learning platforms are promising ways to ensure the professional development of teachers during the pandemic.

Keywords STEM education · Lesson study model · Teacher · Lesson plan · Distance learning

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1 Introduction

Advances in information and communication technology (ICT) have changed how we view education. This new perspective has paved the way for changes in educational institutions and the integration of ICT into education (Turan et al., 2013). Moreover, the COVID-19 pandemic has accelerated the integration of ICT into educational environments. These developments have also had ramifications on professional development, which has become harder to achieve since the pandemic due to the lack of face-to-face learning. Therefore, we need to design flexible, affordable, and quality distance learning programs to help teachers develop professional skills during the pandemic (Powell & Bodur, 2019). There are some concerns about distance learning (Parson et al., 2019), but well-planned distance learning can yield effective results for teachers (Darling-Hammond et al., 2017; Powell & Bodur, 2019). Therefore, we need flexible, easy-to-access, collaborative, and multidisciplinary distance learning environments to meet teachers' professional needs. Researchers have recently focused on strategies to help teachers improve themselves professionally (Sadler et al., 2020). However, those strategies are far from perfect, preventing teachers from realizing themselves in the professional sense. Therefore, we should concentrate on distance learning processes to overcome those challenges.

We provided teachers with an LSM-based professional development program to help them develop high-quality STEM lesson plans for distance learning and then investigated what they thought of the program. In other words, we presented the program to teachers to improve their lesson planning skills and overall professional competence and then discussed their views of the model. We consider this study important because it will help teachers develop professional skills and better lesson plans. Another original aspect of this study is that it aimed to assist teachers in developing STEM education skills based on distance learning during the pandemic. Some studies discuss what teachers and preservice teachers think about STEM education (Arslan & Yıldırım, 2020; Karakaya et al., 2018; Margot & Kettler, 2019; Park et al., 2017; Wang et al., 2011). Many other studies focus on lesson planning based on LSMs (Angelini & Alvarez, 2018; Aykan, 2019; Fernandez, 2010; Lamb, 2015; Lyding, 2012; Skott & Moller, 2017). However, those studies deal with STEM education and LSMs separately. This is the first study to integrate an LSM into STEM education and develop a program (LSM + STEM) in which teachers plan lessons, brainstorm about them, and then revise them. We then interviewed them to gain insight into their views of the program in order to evaluate the effectiveness of distance learning-based STEM education, LSM activities, and lesson planning processes. We also looked into what challenges teachers faced, what evaluation and assessment methods they used, and what strategies, methods, and techniques they implemented. The main research question was, "What do teachers think about the LSM program integrated into distance learning-based STEM education?" The study also sought answers to the following subquestions:

(1) What do teachers think about distance learning?
(2) What do teachers think about the LSM + STEM program?
(3) What are the implications of the LSM + STEM program on lesson planning processes?
(4) What are the implications of the LSM + STEM program on professional development?
(5) What are the implications of the LSM + STEM program on STEM teaching?
(6) What do experts think about lesson planning based on the LSM + STEM program?

(7) What do videotapes tell us about lesson planning based on the LSM + STEM program?

2 Literature Review

2.1 Distance Learning and Professional Development

More than 200 countries have implemented drastic changes in their education systems since the onset of the pandemic. Novel Coronavirus disease (COVID-19) broke out in Wuhan, China, at the end of 2019 and has taken hold of the whole world since then. This global shock has forced countries to focus on alternative educational strategies (Sintema, 2020). The pandemic has caused a sudden shift from conventional classroom teaching to distance learning, leaving teachers face to face with numerous challenges that they had never experienced before. Distance learning has become so popular among all educational institutions that it has started to affect the professional development processes that teachers go through. Teachers interested in developing professional skills have turned to distance learning programs (Sadler et al., 2020). One of those programs is Lesson Study (LS), a Japanese educational practice model. LSM-based face-to-face learning has been replaced by distance learning since the onset of the pandemic (Huang et al., 2021).

2.2 STEM Education

STEM education incorporates the fields of science (S), technology (T), engineering (E), and mathematics (M) and relates them to daily life. Some countries (UK, USA, Turkey, etc.) have integrated STEM into formal and informal education to improve science and math literacy, teach 21st-century skills, and facilitate collaboration between schools and industries (Kim, 2019). Teachers are vital to education, and therefore, responsible for putting STEM education into practice (Timur & İnançlı, 2018; Türk et al., 2018; Yıldırım, 2021). Teachers who can apply STEM education are more likely to have students with high academic performance. However, this also means that only those with a sound grasp of STEM education can integrate it into their lectures (Pang & Good, 2000). Teachers with little knowledge of STEM fields are more likely to have negative attitudes towards them (Jamil et al., 2018). For example, preschool teachers with low self-perceived competence have more difficulty teaching science and math (Timur, 2012). Therefore, teachers should first develop competence before trying to incorporate STEM education into formal and informal education. Teachers' STEM education performance depends mostly on their strategies and methods (Okur Akçay, 2015) because the more effective the strategies and methods, the more likely it is that students can learn. Lesson planning turns STEM education from an abstract concept into a practical and applicable model. Lesson plans help teachers deliver class and perform in-class activities systematically (Kablan, 2012). Therefore, teachers interested in putting STEM education into practice systematically should prepare lesson plans.

2.3 Lesson Study

Countries put great effort into making teacher training effective (Aykan, 2019). Lesson Study (LS) is a professional development model that has been popular in recent years. It

provides teachers with the opportunity to develop professional skills (Dudley, 2015; Saito & Atencio, 2013). American and European researchers have a growing interest in the education systems of Singapore, China, South Korea, and Japan because those countries successfully implement LS to improve academic performance, especially in PISA (Programme for International Student Assessment) and TIMMS (Trends in International Mathematics and Science Study) exams (Dudley, 2013; Fujii, 2014; Lewis, 2002; Norwich & Ylonen, 2013). Lesson Study, which is a literal translation of "*jugyo kenkyu*," is a Japanese model of teaching improvement process (Tan, 2014) that consists of three steps: (1) teachers plan a lesson together, and one of them put it into practice, (2) other teachers observe it and take notes, and (3) they all come together again and revise the lesson plan (Lewis, 2009; Lewis et al., 2011). Lesson Study promotes collaboration, helping teachers develop skills and plan lessons better (Cheng & Yee, 2012; Fernandez, 2010).

Equipped teachers and practical lesson plans have positive repercussions on teaching activities. In Japan, Lesson Study is mainly used for the professional development of math and science teachers. Lesson Study provides an opportunity for collaborative professional development through which teachers can analyze science course content and formulate new strategies (Baricaua Gutierez, 2016). Therefore, STEM teachers should be offered a Lesson Study Model (LSM) to allow them to collaborate and share their knowledge and experience, resulting in better lesson plans and more equipped teachers.

3 Method

3.1 Design

This paper adopted a case study research design to conduct an objective, valid, and reliable analysis of the impacts of the LSM on STEM education during distance learning. A case study is a qualitative research design used to understand and interpret a phenomenon in its natural setting (Merriam, 2009). We aimed to explore what teachers thought about the implications of the LSM on STEM education during distance learning. Our goal was to approach the topic from a holistic perspective. Therefore, we regarded each participant as a case.

3.2 Participants

Participants were recruited using criteria sampling, which is a non-probability purposive sampling method. Criteria sampling involves the selection of a sample that meets a predetermined set of criteria (Yıldırım & Şimşek, 2011). It is a time- and cost-efficient method by which researchers select participants most suited to the research purpose (Patton, 2002). We selected science teachers who enrolled in distance learning and interviewed them after the LSM + STEM program. The inclusion criteria were as follows: (1) having completed distance learning, (2) planning lessons based on the program, (3) using the lesson plans in their lectures, and (4) volunteering. The sample consisted of 24 science teachers (19 women and five men) who met the inclusion criteria. Twenty participants had 1–10 years of experience, while the remaining had 11–20 years of experience. Participants were assigned pseudonyms (Ali, Aybüke, etc.) to assure anonymity.

3.3 Instruments

3.3.1 Teacher Interview Questionnaire

Semi-structured interviews were conducted to determine participants' views of distance learning, STEM education, lesson planning, and the LSM. Participants were interviewed using the Teacher Interview questionnaire (TIQ) developed by the researchers. The questionnaire consisted of eight easy-to-understand and open-ended questions. The questionnaire was sent to two experts, one of whom had a Ph.D. degree and research on STEM education, while the other had a Ph.D. degree in educational programs and teaching and research on LS. The questionnaire was revised based on their feedback. A pilot study was conducted with three teachers to determine the intelligibility of the items. The questionnaire was completed based on their feedback (Appendix 1).

3.3.2 Videotapes

To corroborate the interviews and expert opinions, we video-recorded (a total of 24 h) participants put their lesson plans into practice during distance learning. The videos were supported by participants' views and experts' observations.

3.3.3 Lesson Plans

Participants' lesson plans based on the cyclical process of the LSM were used to assess their STEM teaching. The lesson plans were analyzed to look into the implications of the LSM on STEM teaching and were also used to corroborate the qualitative data and evaluate STEM teaching performed by participants. They were examined based on the criteria in Table 1.

Table 1 Evaluation criteria for lesson plans

	Criterion	Subcriteria
1	Professional Skill	Planning education
		Creating learning environments
		Managing the learning process
		Evaluation and assessment
2	STEM Integration	Content knowledge
		Integrating disciplines
		Connecting with everyday life
		Level-appropriateness
3	21st-century skills	Effective communication
		Critical thinking
		Empathizing
		Collaboration
		Problem-solving
		Creativity
4	Attitudes and Values	Democratic attitude
		Respect

3.3.4 Observation

Observation is a research method used to explore a group of people's attitudes and behaviors towards an event or phenomenon in any or regulated setting or to recognize the formal dimension of a topic of interest (Baltacı, 2019). Observation improves the validity and corroborates interview results (Baxter & Jack, 2008). This study involved observations in enhancing the validity and checking whether different types of qualitative data confirmed each other. Two experts with a Ph.D. in LS made the observations based on predetermined criteria. The observations were based on the evaluation criteria for lesson plans (Table 1).

3.4 Data Analysis

Qualitative data were collected online through interviews. Each interview took 15–21 min (432 in total) and was recorded. The interviews were transcribed and then analyzed using content analysis. The content analysis was based on the five phases proposed by Kuckartz (2014). Two experts (one of whom had a Ph.D. degree and research on STEM education, while the other had a Ph.D. degree in educational programs and teaching and research on LS) developed themes, categories, and codes based on the content analysis results. They identified the parts on which they disagreed and discussed them until they reached a consensus. This process ensured intercoder reliability (Miles et al., 2014), which was 84%. The intercoder agreement should be at least 80% (Patton, 2002). Therefore, the resulting agreement was adequate.

Permission was obtained from participants to videotape the interviews. Two experts analyzed the interviews. They identified the parts on which they disagreed and discussed them until they reached a consensus. This process ensured intercoder reliability regarding video analysis (Miles et al., 2014). The intercoder reliability was 80%, which was adequate (Patton, 2002).

The lesson plans were analyzed based on the evaluation criteria (Table 1). The experts identified the codes on which they disagreed and discussed them until they reached a consensus. This process ensured intercoder reliability regarding the analysis of the lesson plans (Miles et al., 2014). The intercoder reliability was 84%, which was adequate (Patton, 2002).

3.5 Procedure

This study was conducted with science teachers who attended distance learning for 59 h. The objective of the training was to help them use the LSM to develop STEM lesson plans. Table 2 shows the training and data collection process.

3.6 Results

The themes, categories, and codes were presented in tables. Direct quotations were used to provide a coherent picture of participants' views and allow readers to interpret the findings.

Table 2 Training and data collection process

No	Duration (hour)	Content	Explanation
1	1	Introduction	Informing about the content of distance learning
2	10	The onset of STEM education	Training based on the education model of STEM teacher institutes
3	10	Presenting STEM education applications	Sample STEM education applications
4	2	Introducing the LSM	Introducing the LSM and integrating it into STEM lesson plans
5	4	Lesson planning for STEM education	Teaching how to plan lessons tailored to STEM education
6	4	Lesson planning initiation and presentation	Planning lessons in groups and presenting them
7	12	Presenting lesson plans	Lesson plan presentation (Groups 1 and 2)
			Lesson plan presentation (Groups 3 and 4)
			Lesson plan presentation (Groups 5 and 6)
8	4	Revising the lesson plans and presenting them again	Reviewing and changing the lesson plans based on group feedback
9	12	Presentation	Lesson plan presentation (Groups 1 and 2)
			Lesson plan presentation (Groups 3 and 4)
			Lesson plan presentation (Groups 5 and 6)
10	–	End of evaluation	Termination of lesson planning and research
11	7.2	Interviews	Interviews

Participants received 59 h of training on lesson planning (24 h) and LSM and STEM education (35 h). They developed lesson plans in groups

Table 3 Why participants prefer distance learning

Themes	Codes	Quotes
Why participants prefer distance learning	Learning STEM education (n = 12)	I attended this online training to learn about STEM education. Emine
	Professional development (n = 8)	To overcome my weaknesses and to develop professional skills. Işılay
	Experienced instructor (n = 7)	I wanted to attend it to benefit from the instructor's experiences. Esin
	COVID-19 Pandemic (n = 6)	I wanted to attend this training because of the pandemic. Seda
	Flexibility (n = 5)	It's because the training had no time limit. Recep
	Affordable (n = 4)	It was cost- and time-effective. Gökhan

Participants preferred distance learning for different reasons. They stated that they attended it because they wanted to learn STEM education from experienced instructors to improve themselves professionally (Table 3)

Table 4 Participants' views of distance learning

Themes	Categories	Codes	Quotes
Participants' views of distance learning	Positive	Professional development (n = 10)	I think it's good for teachers' professional development. Filiz
		No spatial limit (n = 8)	It's a great advantage that you don't have to step outside the comforts of your home to attend it. Ada
		Online (n = 6)	It is important that the lessons take place online. Ali
		Promoting interaction (n = 2)	I attended it to meet different people. Serkan
		Exchange of information (n = 2)	It allows us to exchange information. Sude
		Flexibility (n = 4)	It's easy to listen to the lessons because it is flexible. Dilek
		Facilitating teamwork (n = 3)	Distance learning allows you to work with others. Emine
		Watching classes online (n = 4)	It's nice that I can watch the lessons online later on. Aybüke
		A design responding to needs	It allows us to take courses that suit our needs. Esin
		Sharing experiences (n = 6)	It allows us to share experiences with different teachers. Oylum
	Negative	Unlike face-to-face learning (n = 3)	It being online is a disadvantage because it is not as effective as face-to-face learning. Ayça
		Infrastructure issues (n = 2)	Since it's online, so you sometimes have to deal with connection issues. Serkan

Participants had positive and negative views of distance learning. However, most of them held positive opinions about it (Table 4)

Table 5 Challenges of distance learning

Themes	Codes	Quotes
Challenges	Internet connection issues (n = 14)	The Internet connection issues during the training. Seda
	Power outages (n = 7)	The power outages during the training were one of the biggest hurdles. Gül
	Lack of resources (n = 4)	There are too few resources to turn to. Esra
	Long hours of class (n = 3)	Long hours of class make me tired. Filiz
	Communication problems (n = 2)	We sometimes have communication problems because it is online. Funda
	Health problems (n = 2)	Health problems held me back. Çağla

Participants had to deal with Internet connection issues and power outages during distance learning. They also complained that there were not enough resources to turn to (Table 5)

3.7 Participants' Views of Distance learning

The first subquestion investigated participants' views of distance learning (Tables 3, 4, 5).

3.8 Participants' Views of the Lesson Study Model and STEM Education

The second subquestion addressed participants' views of the LSM (Table 6).

3.9 Participants' Views of STEM Education

The second question of the second subquestion looked into what participants thought about STEM education within the scope of distance learning (Table 7).

3.10 Contribution of Lesson Study to STEM Education

The third question of the second subquestion focused on participants' views of the contribution of the LSM to STEM education (Table 8).

3.11 The Effect of Lesson Study on STEM Lesson Planning

The first question of the third subquestion investigated participants' views of the effect of the LSM on STEM lesson planning (Table 9).

3.12 Challenges of Lesson Planning

The second question of the third subquestion focused on what challenges participants faced when planning STEM lessons (Table 10)

3.13 The Effect of the Lesson Study Model on Professional Development

The first question of the sixth subquestion addressed how participants thought the LSM affected their professional development.

3.14 The Effect of the Lesson Study Model on Pedagogical and Content Knowledge

The first question of the fourth subquestion investigated how participants thought the LSM affected their pedagogical and content knowledge (Table 11).

Table 6 Participants' views of the lesson study model

Themes	Categories	Codes	Quotes
Participants' views of lesson study	Professional development	Critical perspective (n = 3)	It [Lesson Study] helped us approach the lesson planning process from a critical perspective. Recep
		Time management (n = 2)	It helped me manage time. Ayça
		Collaboration (n = 2)	It allowed us to work together to plan lessons. Gül
		Improving self-assessment (n = 2)	It promoted self-criticism. Bilge
		Different perspective (n = 2)	It helped us develop different perspectives and improve those perspectives. Funda
		Doing research (n = 1)	It pushed us to do research to come up with lesson plans. Filiz
		Facilitating classroom management (n = 1)	It promoted classroom management. Ali
	Lesson plan	Overcoming shortcomings of the lesson plan (n = 5)	I was able to see the shortcomings of my lesson plan and fix them. Ayla
		Quality lesson plan' (n = 5)	I think it helped us plan lessons. Mehmet
		Planned teaching (n = 2)	It helped us plan the lesson planning process. Sude
		Level-appropriate (n = 2)	It helped us plan lessons tailored to students' comprehension skills and age. Dilek
		İnstant feedback-correction (n = 1)	I found the immediate feedback and correction useful. Seda
		Goal-directed plan (n = 1)	It helped us plan lessons in a way that served the teaching purpose. Gökhan
	Creating learning environments	Observing the classroom environment (n = 1)	This model may help us observe classroom environments. Esin
		Efficient teaching environment (n = 1)	It can help us provide a rich classroom environment and get successful results. Serkan
	Communication and collaboration	Lack of personal criticism (n = 2)	Lesson plans should be criticized, not people. Oylum
		Effective communication (n = 1)	It can provide effective communication. Gül
		Expert feedback (n = 4)	Receiving expert opinions during the lesson planning process. Emine

Participants' views of the LSM were grouped under four categories. They stated that the LSM provided expert feedback and helped them adopt a critical perspective, see their shortcomings, develop solutions, and plan lessons better. They also noted that an LSM should involve effective communication instead of personal criticism (Table 6)

3.15 Target LSM Skills

The second question of the fourth subquestion focused on participants' views of target LSM skills (Table 12).

3.16 The Impact of the LSM on STEM teaching

Within the scope of the fifth subquestion, the lesson plans were taken into account to look into the impact of the LSM on STEM teaching. The lesson plans were analyzed according to the criteria given in Table 1 (Tables 13, 14).

3.17 Expert Observation

The sixth subquestion analyzed the experts' observations of the presentation of the lesson plans. Table 15 shows the expert observations.

3.18 Experts' Views of Videotapes

The seventh subquestion concentrated on experts' observations concerning the videotapes. Table 16 shows the experts' views of the videotapes.

4 Discussion and Conclusion

This study focused on the effect of a Study Lesson Model (LSM) on teachers' lesson plans tailored to STEM education. We analyzed participants' views under subquestions and reached the following conclusions:

The first subquestion addressed participants' views of distance learning. They reported some pros and cons of distance learning. As for pros, they stated that distance learning promoted professional development and allowed them to share information online whenever and wherever they wanted. They also noted that they preferred distance learning because they wanted to learn about STEM education and have related experiences to improve themselves professionally. Burns (2011) maintains that distance learning helps teachers develop professional skills. DeNeui and Dodge (2006) also stress that the greatest advantage of distance learning is that it allows students to participate in their learning whenever and wherever they want to. As for cons, our participants stated that they sometimes had to deal with power shortages and Internet connection problems. They also had difficulty accessing different sources. DePaepe et al. (2018) also claim that the lack of resources is one of the major challenges of distance learning. Our results are consistent with the literature (Horspol & Lange, 2012; Chao et al., 2006).

The second subquestion looked into what participants thought about the LSM in distance learning. They stated that the LSM contributed to their professional development. This result is consistent with the literature (Aykan, 2019; Barber, 2018; Dudley, 2015; González & Deal, 2017; Mitchell, 2017). For example, Chong and Kong (2012) and

Table 7 Participants' views of STEM education

Themes	Categories	Codes	Quotes
Participants' Views of STEM education	21st-century skills	Creativity (n = 3)	I think that it [STEM education] helps improve creativity. Sude
		Critical thinking (n = 3)	It contributes to the development of critical thinking. Dilek
		Collaboration (n = 2)	It promotes collaboration. Seda
		Problem-solving (n = 2)	It helps us solve everyday life problems. Emine
	Approaches to learning	Interdisciplinary learning (n = 9)	It promotes interdisciplinarity. Çağla
		Learning retention (n = 6)	It provides learning retention. Aybüke
		Active learning (n = 3)	It allows us to participate in the process actively. Işılay
		Concrete learning (n = 3)	It promotes concrete learning. Ali
		Meaningful learning (n = 2)	It provides meaningful learning by allowing us to use different courses and disciplines appropriately. Ada
		Learning by doing and living (n = 1)	It is based on learning by doing and living. Mehmet
	Conceptual teaching	Teaching engineering concepts (n = 2)	It lays the foundation for engineering from early childhood. Gökhan
		Teaching basic concepts (n = 1)	It helps teachers to teach basic STEM concepts. Serkan
		Teaching math concepts (n = 1)	It helps integrate math. Recep
	Cognitive Skills	Transfer-Association (n = 2)	It facilitates interdisciplinary collaboration and knowledge transfer to solve problems. Ayla
		Raising awareness (n = 2)	It raises awareness. Ayça
	Affective skills	Drawing attention (n = 1)	It draws attention to different things. Gül
		Laying the groundwork for different perspectives (n = 1)	It is nice to look at things from a different perspective. Bilge
		Self-confidence (n = 1)	It helps us actively participate in the process and build up self-confidence. Filiz
		Challenging prejudices (n = 1)	It is useful in dispelling prejudices surrounding science. Esra

Participants' views of STEM education were grouped under five categories: 21st-century skills, approaches to learning, conceptual teaching, and cognitive and affective skills. Participants stated that STEM education promoted creativity and interdisciplinary learning, and helped them teach engineering concepts, transfer knowledge, and pay attention to different topics (Table 7)

Table 8 Participants' views of the contribution of the LSM to STEM education

Themes	Categories	Codes	Quotes
Contribution of the LSM to STEM education	Contribution to pedagogical and content knowledge	Pedagogical knowledge (n = 4)	I learned different methods, techniques, activities, and materials. Gül
		Improving content knowledge (n = 2)	It helped me improve my STEM knowledge and experience. Ali
		Integration knowledge (n = 1)	It allowed us to use knowledge from different disciplines at the same time. Ayça
	Contribution to lesson planning	Revising the lesson plans (n = 1)	It helped us revise the incomplete and wrong STEM lesson plans. Mehmet
		Quality lesson plan (n = 3)	It helped us draw up better STEM lesson plans. Funda
	Contribution to 21st-century skills	Creativity (n = 1)	It made us more creative. Filiz
		Critical thinking (n = 1)	It helped us approach the process critically. Serkan
		Collaboration (n = 1)	It allowed us to collaborate in harmony. Ayla

Participants believed that the LSM made significant contributions to STEM education. Their views were grouped under three categories (Table 8)

Table 9 Participants' views of the effect of lesson study on STEM lesson planning

Themes	Categories	Codes	Quotes
Repercussions of the LSM	Contribution to professional development	Pedagogical knowledge development (n = 4)	It helped me learn new assessment and evaluation methods. Recep
		Benefits of professional collaboration (n = 3)	Some teachers talked about collaboration. Beyza
		Self-assessment (n = 1)	It promoted self-criticism. Sude
		Different perspective (n = 5)	It helped us look at lesson plans from a different perspective. Dilek
		Teaching key points (n = 2)	Sharing experiences helped me realize what the key points might be. Mehmet
		Critical perspective (n = 4)	It helped me approach lesson plans from a critical point of view. Dilek
	Contribution to lesson planning	High-quality STEM plan (n = 11)	It helped me see the shortcomings of the lesson plans and fix them. Damla
		Recognizing the weaknesses of a lesson plan (n = 4)	We got to see the shortcomings of the lesson plans. Seda
		Interdisciplinarity (n = 3)	It helped us make a connection between courses. Emine
		Student level-appropriate (n = 2)	It helped me prepare lesson plans tailored to students' levels. Çağla
		Recognizing the strengths of a lesson plan (n = 1)	It made me realize the strengths and weaknesses of the lesson plans. Aybüke
		Instant feedback-correction (n = 1)	I think it is nice to receive instant feedback and correction to plan lessons. Işılay

Participants believed that the LSM affected STEM lesson planning positively. They stated that the LSM helped them adopt a different perspective and prepare high-quality lesson plans (Table 9)

Table 10 Challenges of lesson planning

Themes	Categories	**Codes**	Quotes
Challenges	Of teacher origin	Criticism brought against teachers (n = 2)	It's the lesson plans that should be criticized, not the teachers. Ali
		Uncalled-for criticism (n = 1)	Criticism should not go too far. Esin
		Group work problems (n = 1)	Group members should make concise and clear assessments. Oylum
	Of environment and condition origin	Lack of material (n = 3)	We couldn't realize some ideas due to the lack of material. Gökhan
	Lack of knowledge	Inability to plan lessons (n = 9)	We didn't have much experience in planning STEM lessons. Serkan
		Lack of knowledge (n = 2)	At first, we didn't know much about lesson planning. Esra
		Inability to integrate different disciplines (n = 1)	It was at first hard to incorporate different disciplines. Ayla
	Time	Time management issues (n = 3)	We managed time better as we had more experience. Ada
		Inability to plan the process (n = 3)	A good planning process should precede the model. Filiz

Participants remarked that they faced different problems during lesson planning. Those problems were grouped under four categories: Of teacher origin, of environment and condition origin, lack of knowledge, and time (Table 10)

Table 11 Participants' views of the effect of the lesson study model on pedagogical and content knowledge

Themes	Categories	Codes	Quotes
Pedagogical and content knowledge	Teaching methods and techniques	Using different techniques (n = 9)	We used different methods and techniques. Funda
		Student level-appropriate (n = 4)	We tried to come up with lesson plans tailored to students' levels. Bilge
		Theory of multiple intelligences (n = 1)	We used the theory of multiple intelligences to address targeted learning outcomes. Ayça
	Approaches to learning	Individual learning (n = 2)	We paid attention to individual differences. Gül
		Meaningful learning (n = 1)	It promotes meaningful learning. Serkan
		Learning by doing and living (n = 1)	This model helped us learn by doing and living. Gökhan
		Learning retention (n = 2)	Better lesson plans ensure learning retention. Mehmet
		Active learning (n = 2)	Active participation in learning provides learning retention. Beyza
	Efficiency in teaching	Quality lesson plan (n = 10)	I think that the LSM helped us plan STEM lessons better. Sude
		Motivation (n = 1)	I can choose motivating activities tailored to students' levels. Dilek
	Assessment and evaluation	Process evaluation (n = 7)	I found evaluating the process to be more effective. Seda
		Using alternative assessment and evaluation methods (n = 4)	We learned about new evaluation and assessment methods. Ali
		Developing a different perspective (n = 3)	It helped me develop different perspectives on assessment and evaluation. Recep
		Absolute evaluation (n = 1)	It helped me learn about absolute evaluation. Esin
		Self-assessment (n = 1)	I got to use the assessment and evaluation methods I thought I would never use. Oylum
		Evaluation of results (n = 2)	We saw that we need to do more than just evaluating results. Damla
		Project evaluation (n = 1)	It helped me develop a different perspective on project evaluation. Emine
		Evaluation of the process and results (n = 1)	We learned about methods where we got to evaluate both the process and results. Çağla
	Guidance	Guiding students (n = 1)	It allows us to see students' shortcomings and guide them. Aybüke
	Class management	Time management (n = 4)	We managed time more efficiently after the first couple of applications. Işılay
		Promoting interaction (n = 1)	The LSM promoted group interaction. Damla
	Content knowledge	Engineering knowledge (n = 1)	The LSM and STEM helped us gain engineering knowledge and experience. Gül
		Math knowledge (n = 1)	I think that it helped me develop abstract thinking skills about math and geometry. Recep

Participants' views of the effect of LS on pedagogical and content knowledge were grouped under seven categories. Participants stressed that the LSM helped them use different techniques, manage time more efficiently, draw up better lesson plans, and acquire engineering and math knowledge (Table 11)

Table 12 Participants' views of target LSM skills

Themes	Subthemes	Categories	Codes	Quotes
Target Skills	21st-century skills	Learning and Innovation Skills	Creativity and innovation (n = 1)	It [the LSM] helped us plan STEM lessons more creatively. Bilge
			Problem-solving (n = 4)	It helped us develop problem-solving skills. Dilek
			Collaboration (n = 7)	It's a model that encourages us to move beyond individuality and work with others. Mehmet
			Critical thinking (n = 8)	A model that directly improves our critical thinking skills. Gül
		Life and Career Skills	Entrepreneurship and self-guidance (n = 2)	I've gained a lot in terms of entrepreneurship. Damla
			Leadership and responsibility (n = 1)	With the LSM, we all had a chance to contribute to the work. Aybüke
			Social and intercultural skills(n = 1)	We, teachers, got to create a sharing environment. Işılay
	Scientific process skills	Fundamental skills	Observation (n = 1)	A model that improves my ability to make an observation. Esin

Participants' views of target LS skills were grouped under two categories: 21st-century skills and scientific process skills. They suggested that the LSM helped them develop some of the 21st-century skills (critical thinking and collaboration) and observation skills (scientific process) (Table 12)

Table 13 The Analysis of the first lesson plans

Groups							
Criterion	Subcriteria	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Professional Skill	Planning education	✓	✓	✓	✓	✓	✓
	Creating learning environments	✓	✓	✓	✓	✓	✓
	Managing the learning process						
	Evaluation and assessment	✓	✓	✓	✓	✓	✓
STEM integration	Content knowledge	Lack of math knowledge	Lack of technological integration	Lack of engineering knowledge	Lack of engineering knowledge	Lack of math knowledge	Lack of technological and engineering knowledge
	Integrating disciplines						
	Connecting with everyday life	✓	✓			✓	
	Level-appropriateness	✓	✓	✓	✓	✓	✓
21st-century skills	Effective communication	✓	✓		✓		✓
	Critical thinking	✓	✓	✓	✓	✓	✓
	Empathizing	✓	✓		✓		✓
	Collaboration	✓	✓		✓		✓
	Problem-solving	✓	✓		✓		✓
	Creativity	✓	✓	✓	✓	✓	✓
Attitudes and values	Democratic attitude						
	Respect						

The first lesson plans showed that participants lacked professional skills and had problems with STEM integration and attitudes and values (Table 13)

Table 14 The Analysis of the second lesson plans

Groups							
Criterion	Subcriteria	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Professional skill	Planning education	✓	✓	✓	✓	✓	✓
	Creating learning environments	✓	✓	✓	✓	✓	✓
	Managing the learning process	✓	✓	✓	✓	✓	✓
	Evaluation and assessment	✓	✓	✓	✓	✓	✓
STEM integration	Content knowledge	✓	✓	✓	✓	✓	✓
	Integrating disciplines	✓	✓	✓	✓	✓	✓
	Connecting with everyday life	✓	✓	✓	✓	✓	✓
	Level-appropriateness	✓	✓	✓	✓	✓	✓
21st-century skills	Effective communication	✓	✓		✓	✓	✓
	Critical thinking	✓	✓	✓	✓	✓	✓
	Empathizing	✓	✓		✓	✓	✓
	Collaboration	✓	✓		✓	✓	✓
	Problem-solving	✓	✓	✓	✓	✓	✓
	Creativity	✓	✓	✓	✓	✓	✓
Attitudes and values	Democratic attitude						
	Respect						

Participants had less difficulty with professional skills, STEM integration, and 21st-century skills in the second lesson plans than in the first ones. However, the second lesson plans indicated that participants still had problems with attitudes and values (Table 14)

Dudley (2011) reported that LS contributed to teachers' professional development. Participants also noted that the LSM helped them draw up better lesson plans. Research also shows that LS improves teachers' ability to develop lesson plans (Aykan, 2019; Carroll, 2013; Lyding, 2012; Mostofo, 2014). Aykan (2019) found that the LSM had positive effects on the lesson planning process. Participants remarked that LS provided them with the opportunity to develop communication and collaboration skills, which is consistent with the literature (Aykan, 2019; Dudley, 2011; Skott & Moller, 2017; Kanauan & Inprasitha, 2014). For example, Skot and Moller (2017) concluded that LS helped teachers communicate and collaborate more effectively. Participants believed that the LSM helped them provide better learning environments, which is consistent with the results of Marble (2007) and Pektaş (2014). The challenges of lesson planning for participants were inexperience and time management issues. Studies also report that LS has some disadvantages (Aykan & Dursun, 2020; Demir et al., 2013).

The second question of the second subquestion addressed participants' STEM education tailored to distance learning. Their opinions were grouped under five categories: "21st-century skills," "approaches to learning," "conceptual teaching," "cognitive skills," and "affective skills." The first category included creativity, critical thinking, collaboration, and problem-solving skills. The second category was about interdisciplinarity, learning retention, active learning, meaningful learning, and learning by doing and living. Under

Table 15 Expert observations

Themes	Categories	Codes
Expert observations	Professional skills	Sharing knowledge (n = 1)
		Recognizing the shortcomings of the lesson plan
		Student level-appropriate
		Experience
		Detailed planning
		Goal-orientedness
		Criticizing the lesson plan (n = 2)
		Method and technical knowledge (n = 2)
		Assessment and evaluation knowledge (n = 2)
		Time management
		Positive learning environment (n = 1)
	21st-century skills	Effective communication (n = 2)
		Critical thinking
		Empathizing (n = 2)
		Collaboration (n = 2)
		Problem-solving (n = 2)
		Creativity
	Content knowledge	Lack of engineering knowledge
		Lack of math knowledge
		Lack of technological knowledge
		Lack of integration
	Attitudes and values	Hesitancy (n = 2)
		Personal criticism (n = 2)

The experts' observations were grouped under four categories. The experts believed that putting lesson plans into practice had numerous benefits for participants. On the other hand, some participants were hesitant and criticized their colleagues rather than their lesson plans (Table 15)

the third category, participants talked about engineering and math concepts. The fourth category referred to transfer and raising awareness, while the fifth category involved drawing attention, developing a different perspective, self-confidence, and dispelling prejudices. Research also shows that STEM education helps students develop 21st-century skills (Karakaya, & Avgın, 2016; Kim, 2019; Kim & Choi, 2012; Özcan & Koca, 2019) and acquire more knowledge, resulting in high academic performance (Çevik, 2018; Roehrig et al., 2012; Yıldırım, 2020; Yıldırım, & Selvi, 2017). In short, our results are consistent with the literature.

The third question of the second subquestion asked participants what contributions they thought the LSM made to STEM education during distance learning. They noted that the LSM helped them acquire more pedagogical content knowledge, plan better STEM lessons, and develop 21st-century skills. Our results are significant because this is the first study to integrate an LSM with STEM education. We think that LS will make significant contributions to STEM education because it targets non-stop professional development (Aykan & Dursun, 2020; Dudley, 2015) and high-quality lesson plans (Fernandez, 2010). In the LSM process, participants worked together to plan STEM lessons, discussed and modified their plans, and then put them into practice in their lectures. Collaboration enables teachers to

Table 16 Experts' views of videotapes

Themes	Categories	Codes
	Professional skills	Self-assessment
		Sharing knowledge (n = 1)
		recognizing the shortcomings of the lesson plan
		Student level-appropriate
		Sharing experience
		Suggestion for different methods (n = 2)
		Different perspective (n = 2)
		Criticizing lesson plans (n = 2)
		Peer-evaluation
		Assessment and evaluation knowledge (n = 2)
		Positive learning environment (n = 1)
		Unfit for the goal
		Lack of time management
		Level-inappropriate
		Criticizing teachers
	221st-century skills	Effective communication (n = 2)
		Critical thinking
		Social and intercultural skills (n = 1)
		Collaboration (n = 2)
		Problem-solving (n = 2)
		Creativity
	Scientific process skills	Observation
	Content knowledge	Lack of engineering knowledge
		Lack of math knowledge
		Lack of technological knowledge
		Lack of integration

The experts grouped the videotapes under four categories: Professional skills, 21st-century skills, scientific process skills, and content knowledge (Table 16)

develop professional skills and provide high-quality STEM education. Therefore, we can conclude that LS integrated with STEM education results in numerous positive learning and teaching outcomes.

The third subquestion investigated how participants thought the LSM affected the STEM lesson planning process within the scope of distance learning. They stated that the LSM made significant contributions to the lesson planning process and professional development. Numerous studies also point to the positive impact of LS on lesson planning and professional development (Aykan, 2019; Fernandez, 2010; Meiliasari, 2013; Taylor et al., 2005). However, there is no published research integrating LS with lesson planning for STEM education. Planning STEM lessons and putting them into practice is of paramount significance. We think that LSMs can help teachers draw up high-quality STEM lesson plans and equip them with professional knowledge and practical skills.

The second question of the third subquestion focused on the challenges of STEM lesson planning. Participants stated that they had a hard time managing time and had to deal with personal shortcomings (lack of knowledge and experience), and problems of teacher (being

criticized by colleagues) and environment/condition origin (lack of material). This result is consistent with the literature (Aykan, 2019; Chen, 2017; Insprasitha et al., 2015). For example, Chassels and Melville (2009) found that preservice teachers had difficulty managing time while putting LS into practice. Lampley et al. (2018) also reported that teachers were too inexperienced in applying LS. Applying LS poses the same challenges as those of STEM lesson planning with LS.

The fourth subquestion addressed the repercussions of the LSM on professional development. The first question of the fourth subquestion looked into participants' views of the effect of the LSM on pedagogical and content knowledge. They stressed that the LSM taught them about pedagogical learning strategies and teaching and assessment-evaluation methods and improved their ability to manage the classroom, guide students, and teach effectively. Angelini and Alvarez (2018) found that LS contributed to preservice teachers' classroom management and pedagogical knowledge. Participants also remarked that putting the LSM into practice improved their content knowledge significantly. Research shows that LS improves preservice teachers' and teachers' pedagogical and content knowledge (Lamp, 2015; Alvine et al., 2007; Aykan, 2019; Barber, 2018; Copriady, 2013; Dudley, 2011; Fernandez, 2010; Kotelawala, 2012; Sims & Walsh, 2009; Cerbin & Kopp, 2006; Tepylo & Moss, 2011). Therefore, our results are consistent with the literature.

The second question of the fourth subquestion concentrated on participants' views of the target skills of the LSM. They noted that the LSM helped them develop learning and innovation, life and career, and scientific process skills. Research shows that LS provides teachers with the opportunity to develop problem-solving (Isoda, 2010), creativity (González & Deal, 2017), critical thinking (Angelini & Alvarez, 2018), innovation (Akiba & Wilkinson, 2016), observation (Myers, 2012), and entrepreneurship skills (Novendra & Setiani, 2020). Our results are consistent with the literature.

The fifth subquestion addressed the effect of the LSM on STEM teaching. The first lesson plans suggested that participants had problems with professional skills, STEM integration, 21st-century skills, and attitudes and values. They focused on those weaknesses and tried to overcome them in the second lessons plans they drew up based on the LSM + STEM program. However, they still had difficulty incorporating attitudes and values into the second lesson plans or emphasizing them. Our results are consistent with the literature (Chen, 2017; Çevik, 2018; González & Deal, 2017; Lamp, 2015). All in all, we can state that the LSM improved STEM teaching.

The sixth subquestion investigated how experts thought the LSM affected STEM education. The expert observations indicated that the LSM helped participants plan STEM lessons better, develop 21st-century skills (Skott & Moller, 2017), acquire content knowledge (Angelini & Alvarez, 2018; Tepylo & Moss, 2011), and experience professional development (Chen, 2017; Dudley, 2013; Lampley et al., 2018). Research also shows that LS is instrumental in helping teachers develop 21st-century skills. For example, LS improves teachers' creativity (Lamp, 2015; González & Deal, 2017) and collaboration (Skott & Moller, 2017), and communication skills (Chikamori et al., 2013). The experts observed that participants were hesitant at first and criticized their colleagues rather than their lesson plans. However, the more experience they had, the more involved they became in the process (Aykan & Dursun, 2020) and criticized the lesson plans instead of each other. The expert observations were consistent with the interview results. All in all, the results agreed with the literature.

The seventh subquestion asked participants in what way they thought the LSM helped them plan STEM lessons. The results showed that the LSM helped participants develop professional and 21st-century skills and acquire content knowledge. These results were

consistent with the expert observations and interview results. This is the first study to address the effect of an LSM on STEM lesson planning. The results also showed that the LSM promoted professional development, resulting in quality STEM lesson plans. Lewis et al. (2012) also concluded that LS improved teachers' professional skills, making them more capable of coming up with lesson plans and putting them into practice in their lectures. Kuno (2014) and Cheng and Lee (2018) also reported that LS helped teachers develop 21st-century skills. All in all, our results agreed with the literature.

The results concerning the subquestions should be discussed in connection with each other. The results concerning the subquestions corroborate. The interview, observational, and videotape results support each other, resulting in high validity. We think that our results will contribute to the literature and pave the way for further research.

4.1 Implications for Further Research

The results indicated that the LSM integrated with STEM education tailored to distance learning helped teachers develop professional skills. Therefore, authorities should develop LSM-integrated long-term distance learning professional development programs for science teachers. This paper can serve as a guide to that end.

The results also showed that the LSM helped teachers develop better STEM lesson plans tailored to distance learning. Therefore, teachers should be encouraged to use LSMs and distance learning to develop high-quality lesson plans for STEM education. Distance learning can also be used to provide STEM education.

This study focused on distance learning and revealed that teachers held some negative views of distance learning. Researchers should take those views into account and design further studies accordingly. They should also focus on blended learning involving both face-to-face and distance learning.

Teachers had difficulty integrating STEM fields into their lesson plans because they had some gaps in their knowledge. Researchers should develop measurement tools to determine those gaps and provide training.

We also focused on expert opinions to better understand teachers' views and to achieve data diversification. Future studies should also employ data diversification to elicit more information on their topics of interest.

4.2 Limitations

This study had four limitations. First, the results are sample-specific, and therefore, cannot be generalized to the whole population. Second, participants may have expressed predominantly positive views on distance learning because they were already interested in it. Third, Participants received only 59 h of training on lesson planning and LSM and STEM education. Therefore, we recommend that researchers conduct long-term studies. Fourth, this study aimed to help teachers develop professional skills concerning LSM and STEM education through distance learning.

Appendix 1: Teacher Interview questionnaire (TIF)

(1) What do you think about distance learning?
(2) What do you think about the LSM for STEM education?

(3) What do you think about STEM education?
(4) How do you think the LSM affects STEM lesson planning?
(5) How do you think the LSM affects pedagogical and content knowledge?
(6) What contributions do you think the LSM makes to STEM education?
(7) What do you think are the challenges of lesson planning?
(8) What do you think are the LSM target skills?

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