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Exploring teacher development courses in the lens of integrated STEM education: A holistic multiple case study

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Abstract

The implications of how teacher development courses (TDCs) should be designed for integrated STEM education are essential for in-class STEM education practices. This study compares the three TDCs accomplished to support teachers' professional development (PD) for integrated STEM education in terms of pedagogical knowledge, technological knowledge, and strategy. A holistic multiple-case study design was used in this study. Each TDC was considered a case study, and case-specific analyses were made. The findings obtained for each case were then compared. The first TDC included only computer science teachers and showed us the necessity of interdisciplinary work to enhance integrated STEM education. The second TDC demonstrated that this work could be accomplished by combining the content knowledge of teachers from various disciplines; however, the second TDC's drawbacks included identifying real-world problems, a lack of response to the engineering approach for science and mathematics teachers, and the rigidity of the collaborative working strategy. Then, we focused on the role and purpose of "T"echnology. Finally, we gave the teachers learning tasks to work collaboratively with teachers in their disciplines first and teachers from other disciplines later. This study shows how a TDC should be designed effectively to support teachers' PD for integrated STEM education.

Keywords: Professional development, Collaborative professional development, Teacher development, Integrated STEM education, STEM teachers

Introduction

In research on STEM education, one of the STEM disciplines is usually focused on (English, 2016); some studies deal with combinations of different STEM disciplines (Falloon et al., 2020; Li et al., 2020a; Ortiz-Revilla et al., 2020). STEM education projects in the USA mainly focus on separate STEM disciplines, especially mathematics (Li et al., 2020b). Likewise, approximately half of the STEM education research connects to science education when STEM education is mentioned (English, 2016). In recent years, the integration of STEM disciplines for effective STEM education has been further advocated, and the significance of "integrated STEM" education is addressed (Cheng et al., 2020; English, 2016; Johnson, 2013; Martín-Páez et al., 2019; Stohlmann et al., 2012; Thibaut et al., 2018; Zhou et al., 2022). Although STEM education emphasizes linking disciplines, how to achieve this is uncertain in curricula (Morrison et al., 2021). This is because historically, STEM disciplines have always been taught as separate disciplines at the first and secondary school level, and education at schools continues on a single discipline basis (Martín-Páez et al., 2019).

Although integrated STEM education offers great potential for students and teachers, it has some challenges due to a lack of consensus on its implementation (Thibaut et al., 2018). While effectively supporting interdisciplinary education with pedagogical techniques that enrich content and meet curriculum requirements is unknown, it is essential to support teachers' professional development (PD) in this sense, even at the beginner level (Herro & Quigley, 2017; Song, 2020). Teachers should reexamine their beliefs regarding STEM in learning and teaching and move toward interdisciplinary approaches that involve solving real-world problems (Falloon et al., 2020). Teachers' PD regarding integrated STEM education must be supported (Stohlmann et al.,

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2012). There is a tendency for studies that focus on the PD of teachers in integrated STEM education (Baker & Galanti, 2017; Estapa & Tank, 2017; Hudley & Mallinson, 2017; Kelley, Knowles, Holl, & Han, 2020; Ryu, Mentzer, & Knoploch, 2019). In light of these studies, the implications of how teacher development courses (TDCs) should be designed for integrated STEM education are essential for in-class STEM education practices.

The authors of this research have designed and implemented three TDC supported at the national level. The most important feature of these courses is that researchers from different STEM disciplines designed them, and each course was reexamined with the experiences from the previous one. TDCs aimed to develop teachers' knowledge and skills for integrated STEM education. As discussed in the literature, we also tended to work with a single discipline in the first TDC. The first one included only computer science teachers and showed us the necessity of interdisciplinary work to enhance integrated STEM education. The second TDC focused on enabling computer science, science, and mathematics teachers to collaboratively design integrated STEM lessons that focus on real-world problems by connecting STEM disciplines. Based on the experience from the first and the second courses, the third TDC focused on how teachers from different disciplines can collaborate. This study treated each of the three TDCs designed iteratively as cases. It sought to answer the question, "how should a TDC be designed effectively to support teachers' PD for integrated STEM education?".

Literature Review

Integrated STEM Education

Integrated STEM education has been discussed in Sanders's (2009) research on how STEM disciplines interact. Sanders (2009) defines integrated STEM education as learning and teaching approaches in two or more STEM disciplines and/or in a STEM discipline and one or more school subjects. Johnson's (2013, p. 367) definition is as follows: "integrated STEM education is an instructional approach, which integrates the teaching of science and mathematics disciplines through the infusion of the practices of scientific inquiry, technological and engineering design, mathematical analysis, and 21st-century interdisciplinary themes and skills". According to Falloon et al. (2020), the pedagogy and curriculum of STEM education are problem-oriented, project-based, and authentic, real-world scenarios are used as the context for learning, and multiple knowledge and skills are integrated for an activity that focuses on solving a problem, need or an opportunity. Different viewpoints on how disciplinary integration can be accomplished with multidisciplinary, interdisciplinary, and transdisciplinary approaches (English, 2016; Zhou et al., 2022). These perspectives (English, 2016) are; i) can include fundamental concepts and skills that are taught distinctly in each discipline yet are hosted within a common theme; ii) intimately associated concepts and skills from two or more disciplines can be included to deepen understandings; iii) a transdisciplinary approach can be adopted in which knowledge and skills from two or more disciplines are utilized to real-world problems and projects to form the total learning experience. Based on these definitions, three features of integrated STEM education stand out: integration of disciplines, real-world or authentic contexts, and problem-solving (Zhou et al., 2022). This study considers integrated STEM education to integrate a range of conceptual, procedural, and attitudinal contexts in STEM disciplines by linking them together to solve problems presented in authentic contexts.

STEM education improves the application skills in disciplines under its umbrella, provides implementation experience, enhances creativity and technological skills, and increases interest in these areas (Martín-Páez et al., 2019). Integrated STEM education can improve STEM motivation through integrating STEM disciplines (Cheng et al., 2020; Thibaut et al., 2018). With integrated STEM education, STEM disciplines have begun to be combined, engaged in dialogue, and integrated more efficiently in terms of education (Ortiz-Revilla et al., 2020). Integrated STEM attempts to combine science, technology, engineering, and mathematics based on the link between subjects and real-world problems in a single classroom (Stolhman et al., 2012). Integrated STEM education is considered a significant development phase on the road to a skillful future workforce and is seen as a link to future development and prosperity (Zhou et al., 2022). In this respect, it is necessary to focus on basic content information and the interdisciplinary process to ensure STEM integration and improve the profile of all disciplines (English, 2016). In this regard, further research and discussion is needed on the knowledge, experience, and background teachers need (Stolhman et al., 2012).

Teacher Development for Integrated STEM Education

Teachers play a vital role in bringing the potential of integrated STEM education into the classroom. Further research and discussion are needed for teachers to carry integrated STEM education to their classrooms. In particular, teacher development, teaching practices, teacher competencies, and the materials required to implement integrated STEM education must be considered (Stolhman et al., 2012). While a training program that includes STEM integration for pre-service teachers contributes to their planning and implementation skills existing school practices, limited understanding of interdisciplinarity, and lack of role models have proven to be barriers (Ryu et al., 2019). Another barrier is that some disciplines, particularly mathematics and science, emphasize STEM education (Herro & Quigley, 2017). In STEM education, most publicly funded projects in the US focus on individual STEM disciplines, especially mathematics (Li et al., 2020b).

Similarly, it is stated that there is a close relationship between STEM education and science education (English, 2016). There are findings that teachers associate STEM-based activities with science, especially physics, and consider them under physics subjects (Eroğlu & Bektaş, 2016). It can be regarded as a result of teachers' focusing more on their subjects while combining different disciplines. Teachers with various disciplines struggle finding content together and spend more time planning content-specific STEM tasks than determining the content (Brown & Bogiages, 2019). Eight themes were established to support teachers to overcome these challenges: (a) time for collaboration and planning, (b) PD programs, (c) sources, (d) supportive STEM culture, (e) communication between departments, (f) more time for teaching, (g) change in teacher attitudes, (h) manageable classroom sizes (Shernoff, Sinha, Bressler, & Ginsburg, 2017).

The strategies and content of TDCs are among the factors that can be improved at the teacher level, among the factors stated above. In this context, education programs in which disciplines are integrated and 21st-century skills are associated with real-world problems are important (Kurup et al., 2019). The TDC organizers and teachers need to brainstorm and plan together (Brown & Bogiages, 2019). It is necessary to strengthen this collaboration with studies where teachers from different disciplines come together. Professional learning communities with diverse backgrounds contribute to teachers' collective knowledge and pedagogical content knowledge (Vossen et al., 2020). In summary, education programs that focus on real-world problems, link multiple disciplines, and enable teachers to work collaboratively emerge as essential elements in supporting teachers for integrated STEM (Stohlman et al., 2012).

Although strategies to increase the effectiveness of TDCs for integrated STEM have been defined in the literature, it is challenging to put them into practice and realize the expected transformation in teachers. Most teachers have never experienced such a learning experience (Morrison et al., 2021). Teachers' existing teaching habits, pedagogical competencies in the lesson planning, collaborative working skills, and individual differences regarding collaborative working can create facilitating or hindering conditions while implementing the mentioned strategies. Therefore, it is crucial to examine teachers' opinions during the implementation and make revisions accordingly. Thus, it can be ensured that education programs are improved, and PD strategies are optimized.

Present Study

Integrated STEM education is essential to ensure a fairer representation of disciplines. Failure to do so may result in incomplete learning about other disciplines under the name of STEM education. This study aims to compare the three TDCs accomplished in the last three years to support the PD of teachers for integrated STEM education in terms of pedagogical knowledge, technological knowledge, and strategy and to examine teachers' views about these programs. For this purpose, answers were sought to the following questions:

1. How has TDCs' scope for integrated STEM education changed regarding pedagogical knowledge, technological knowledge, and strategy?
2. What are the opinions and suggestions of teachers regarding TDCs?
3. What are the recommendations of the researchers to develop TDCs?

Methodology

Case studies allow for the longitudinal study of a complex situation by broadly defining and identifying its components in their natural environment. In this study, a holistic multiple-case study design was used. The holistic multiple-case design is used when a single analysis unit is being treated with more than one case. In this respect, three TDCs carried out in three consecutive years were determined as units of analysis, and each unit was handled within itself and then compared holistically. The significant advantage of examining multiple units of analysis is that evidence is provided from multiple sources, thus facilitating generalization (Yin, 2009).

Context and Participants

This study tackles three TDCs supported within the scope of national science and society practices and conducted in Turkey in 2018, 2019, and 2020. The scope of the support is to provide teachers with innovative approaches, strategies, methods, and techniques specific to the teaching profession interactively. Based on the analysis of the data obtained from each TDC, experiences gained, and observations made, the design of the TDC in the following year was improved and revised.

All three TDC were designed in modules. Each TDC has experts in the field of computer science, science, and mathematics education who work as faculty members at universities. The authors participated in the process as principal researchers and experts of these TDCs. All experts and teachers came together from different cities in Turkey. TDCs were organized as "education camps", and experts and teachers stayed together during the program. Teachers had the chance to spend time and consistently exchange ideas with experts and colleagues at breakfast, lunch, dinner, and before and after course sessions.

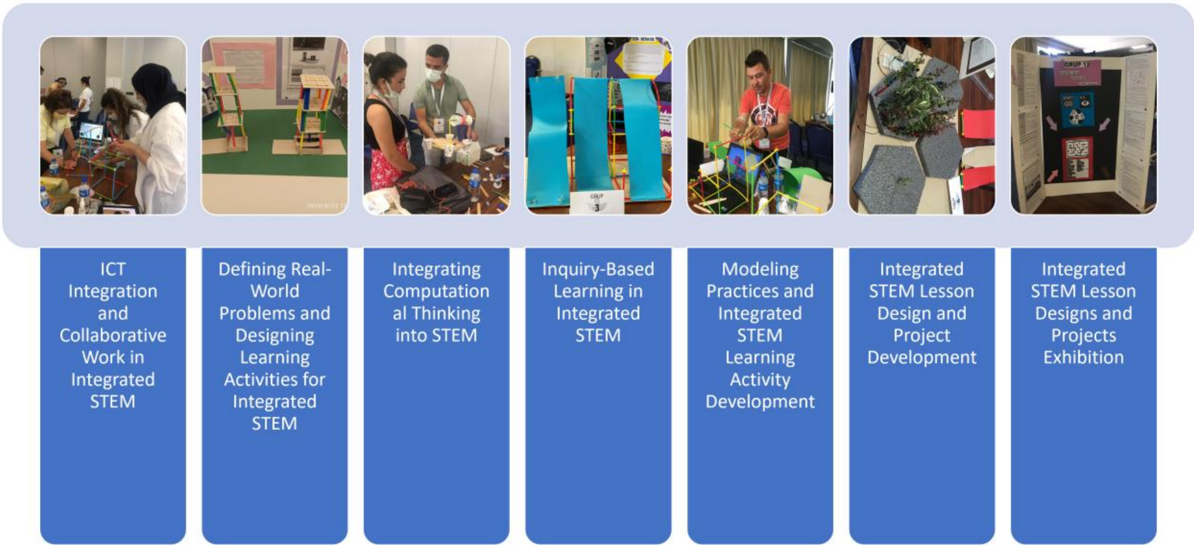

Figure 1. The final version of TDCs' modules

A nationwide call has been made for each TDC. In the application form, teachers were asked about their knowledge and skill levels regarding STEM education in their fields. In addition, teachers were asked to explain their ideas about integrated STEM education and their teaching practices by giving examples. Teachers applied to the program voluntarily, and participants were selected through blind review. This study consisted of teachers who participated in TDCs and worked in secondary schools in various provinces of Turkey.

TDCs were aimed at developing teachers' technological and pedagogical knowledge and skills. Fifty teachers who worked as computer science teachers participated in TDC in 2018. Forty teachers from 26 different cities with science, mathematics, and computer science participated in the program in 2019. Thirty-nine teachers from 19 provinces, science, mathematics, and computer science teachers, attended the program in 2020. Demographic information of teachers is given in Table 1.

According to Table 1, 23 of the teachers who participated in TDC I, carried out in 2018, were female, and 27 were male. When participants' education level was examined, 29 had a bachelor's degree, and 21 had a master's degree. Twenty of the teachers who participated in TDC II, conducted in 2019, were female; 20 were male; 26 had a bachelor's degree, while 14 had a master's degree. 20 of 39 teachers were female, and 19 were male, participated in TDC III in 2020. When the teachers' education levels were examined, 24 of them had a bachelor's degree, and 15 had a master's degree. All TDCs were conducted face-to-face and lasted for six days.

Table 1. Demographic information of teachers participating in TDCs

	TDC-I	TDC-II	TDC-III	Total
Field	50 Computer Science	20 Computer Science	13 Computer Science	83
		10 Mathematics	13 Mathematics	23
		10 Science	13 Science	23
Gender	23 Female	20 Female	20 Female	63
	27 Male	20 Male	19 Male	66
Education Level	29 (Bachelor's Degree)	26 (Bachelor's Degree)	24 (Bachelor's Degree)	79
	21 (Master's Degree)	14 (Master's Degree)	15 (Master's Degree)	50

Data Resources and Analysis

In the study, the education programs of each TDC, field notes were taken by the experts during course sessions, and the focus group interviews with teachers after TDCs were used. Each TDC was considered a case study in the data analysis, and case-specific analyses were made. The findings obtained for each case were then compared. The education programs were examined using document analysis. The first research question was taken as a basis for the documentation analysis, and TDCs were examined in terms of pedagogical knowledge, technological knowledge, and strategy. Data obtained from the field notes and focus group interviews were analyzed with content analysis. More than one researcher kept field notes. After each session, the researchers' notes were compared and discussed by the researchers, and the consensus was achieved. Consensus notes were accepted as data and analyzed.

At the end of each TDC, qualitative data were collected by conducting interviews with volunteer teachers using a semi-structured focus group interview form. The teachers were divided into groups of five and three separate focus group interviews were conducted. In the focus group interview form, there were questions about how TDC contributed to the participants, its suitability for teachers' interests and skills, and suggestions about how it could be more productive. Each interview lasted an average of 30 minutes. Content analysis is about finding concepts and relationships that can explain the data obtained (Yıldırım & Şimşek, 2006). The data analyzed by the content analysis were grouped under three categories:

1. Contribution of TDC to teachers
    a. Change in technological pedagogical content knowledge
    b. Gaining awareness of integrated STEM education
    c. Collaboration among colleagues
2. Teachers' intentions to use innovative methods
3. Recommendations for future TDCs

Content analysis was performed using the NVivo 12 program. The authors used an inductive method to analyze the data. The first author created a precoding list for coding by reading all the data. After that, the second author reviewed the coding and citations, and the analysis was revised. Then the coding was done again by the third author.

Reliability and Validity

Two experts in instructional technologies and science education were consulted during the development of the interview forms. Before the interview, the interview questions were reviewed and developed. The interviews were taped and then transcribed using a voice recorder. As a result, data loss is avoided. To ensure transferability of the data (Miles & Huberman, 1994), the data were thoroughly analyzed and presented with direct quotes. The names of the participants were not used in the direct transfer of data to ensure participant confidentiality. The researchers coded two randomly selected interviews separately (LeCompte & Goetz, 1982). The coders' agreement was calculated to be 87 percent. This rate indicates high consistency (Miles & Huberman, 1994).

Case Study I

Pedagogical Knowledge, Technological Knowledge, and Strategy

TDC-I adopted strategies were workshops, reflective practices, collaborative projects, and lesson planning. TDC-I content included technology integration, games and gamification, engineering design processes, design-based thinking, and interdisciplinary approaches to improving teachers' pedagogical knowledge. Workshops on robotics and Scratch were organized to enhance teachers' technological knowledge. At the end of the program, lesson plans and educational robotics projects as STEM learning activities were developed by teachers collaboratively. The teachers worked in groups of five. Experts and authors who were workshop leaders examined the teachers' artifacts and provided feedback in the process.

Case Study II

Pedagogical Knowledge, Technological Knowledge, and Strategy

In addition to the workshops, reflective practices, collaborative projects, and lesson planning included in the first TDC, peer, and self-assessment strategies were added to TDC-II. The pedagogical approaches adapted in TDC-II differed from TDC-I. In this program, teachers' pedagogical competencies for mathematical modeling and inquiry-based learning approaches were developed within the framework of the interdisciplinary teaching approach. The focus was also on improving teachers' digital competencies by using technological applications such as Algodoo, Python (artificial intelligence applications), Arduino, and Scratch in the learning and teaching process.

In this program, teachers designed integrated STEM lesson plans within the framework of the 5E model in collaboration with other teachers in their group. The teachers worked in groups of four (two computer science teachers, one science teacher, and one mathematics teacher per group). Given that shaping the learning and teaching process with a theoretical foundation and using teaching methods appropriate for this foundation will improve the process' quality (Yıldız, 2017), the 5E model, which consists of the initial words Enter/Engage, Exploration, Explanation, Elaboration, and Evaluation, and is based on the constructivist approach, was used (Bybee, 2009). Using information about their own field, each teacher assumed the position of subject mentor for the group in these arrangements.

Teachers were asked to create products based on STEM learning activities, such as programming and ICT, that they could use to solve real-world problems discussed in the lesson plans (these applications include at least web tools, block-based programming, text-based programming, and robotic programming applications). Besides, each group prepared tables for the lesson plans they designed, showing how the phases of computational thinking in computer science, mathematics, and science are realized and the connections between them. Thus, the teachers created three artifacts: *lesson plans, computational thinking tables,* and *STEM learning activities.*

Throughout the program, experts, workshop leaders, and authors provided feedback during the teachers' collaborative group work, examined the work/product/material they produced, and contributed to their improvement. The program designers prepared checklists to evaluate the teachers' outputs and used them to carry out self-assessment, peer assessment, and expert assessment. The lesson plans that integrate computer science, science, and mathematics education with an integrated STEM education approach were published as e-books as the program's output at the end of the program.

Case Study III

Pedagogical Knowledge, Technological Knowledge, and Strategy

Strategies used in the second program continued in TDC-III. This program aimed to enhance teachers' pedagogical competencies in inquiry-based learning approaches, mathematical modeling, interdisciplinary teaching approaches, and ICT integration. Based on these approaches, the focus was also on strengthening teachers' digital competencies on using technological applications such as Algodoo, Arduino, and Scratch in the learning and teaching process. In this program, a session on computer science unplugged was added instead of artificial intelligence applications. Teachers designed integrated STEM lesson plans within the framework of the 5E model collaboratively with other teachers in their groups. The teachers worked in three groups (one computer science teacher, one science teacher, and one mathematics teacher per group). Each teacher took on the group's subject mentor role in these plans by employing the content information specific to their discipline. Teachers were asked to create products based on STEM learning activities, such as programming and ICT, that they could use to solve real-world problems discussed in the lesson plans (these applications include at least web tools, block-based programming, text-based programming, and robotic programming applications). Besides, each group prepared tables for the lesson plans they designed, showing how the phases of computational thinking in computer science, mathematics, and science are realized and the connections between them. Thus, the teachers created three artifacts: *lesson plans*, *computational thinking tables*, and *STEM learning activities*.

STEM education approach aims to equip students with the knowledge and skills to produce solutions to real-world problems. One of the most challenging issues for teachers in TDC-I and TDC-II was to define a real-world problem that would be subject to and trigger the teaching process and attract the curiosity and interest of the student. Based on this, the "Sustainable Development Goals (SDGs)" defined by the United Nations Development Program were used as a source in TDC-III. Teachers were asked to examine SDGs in groups and determine the subjects and learning objectives to connect with computer science, science, and mathematics teaching programs. Then, teachers were requested to define a real-world problem as a group within the framework of this subject, which requires knowledge and skills of other disciplines. Teachers were then summoned to design it as a STEM learning activity that students should solve under tackled approaches in the program and computer science teachers' programming and ICT applications. Teachers used these activities in the lesson plans they designed.

Throughout the program, experts, workshop leaders, and authors provided feedback during the teachers' collaborative group work, examined the work/product/material they produced, and contributed to their improvement. The program designers prepared checklists to evaluate the outputs prepared by the teachers. Self-assessment, peer assessment, and expert assessment were carried out using the checklists. The lesson plans that integrate computer science, science, and mathematics with an integrated STEM education approach were published as e-books as the program's output at the end of the program.

Findings

The findings begin with examining the initial case following a comparative case analysis. The second and the third cases are presented sequentially by comparing the results obtained from the previous case.

Case Study I

Teachers' Opinions and Suggestions About TDC

All of the teachers who participated in TDC-I stated that preparing a collaborative lesson plan is beneficial for in-class activities. One of the teachers said, "*I think the best part of the program is that the plans we have made will cover a whole year...*". In addition, most teachers stated that applied course sessions increased their courage to use these activities in their classroom. One teacher stated as follows:

> *"In this course, we designed lessons or prepared board games, making learning outcomes more understandable. ... Thus, we gained a comprehensive understanding."*

If teachers' opinions are generalized; they emphasized that TDC-I contributed to the exchange of views with their colleagues. Some of the teachers' statements are as follows:

> *"I think the community in this course I attended is also inspiring in terms of working with my colleagues. Seeing my friends and colleagues as part of a group has been really motivating."*

> *"...Teachers from different cities gathering in one place has shown how valuable it is to come together. We have teachers with profound knowledge here; I have learned from them as much as I have learned from the instructors..."*

Minority of the teachers expressed that allocating more time on collaboration among colleagues would contribute to the improvement of TDC:

> *".. More time could have been devoted to cooperative work. As a group, we could solve problems, meet each other, get acquainted and make a product. I would have loved to see my colleague's point of view and develop our professional network more."*

In addition, most of the teachers thought that the content should be changed so that math and science teachers' subject-matter knowledge could be added to the course:

> *"...robotics and coding, these are concepts that are always talked about. We all know programming, but a fellow teacher talked about the importance of mathematics. This showed me how to move forward in my own PD. I got some book recommendations from him and had lots of ideas about what I can do, how I can integrate them into my lessons..."*

Recommendations by researchers based on field notes

Teachers benefited from designing lesson plans and learning activities and the workshops' activities organized. In addition, it was determined that they were satisfied with working with their colleagues and felt the need to allocate more time to collaboration among colleagues. They encountered difficulties in collaborative lesson planning and designing real-world problems since content knowledge from different disciplines is required. Therefore, it was seen that there is a need to bring together teachers from other disciplines to form collaborative groups among teachers. It was observed that teachers who participated in TDC-I had expectations that more technological content should be included in the education program. Some teachers informed the researchers that there should be field experts from computer engineering in their views on this matter.

Case Study II

Teachers' Opinions and Suggestions About TDC

When teachers' opinions were examined, it was seen that they were in favor of the adopted pedagogical knowledge, technological knowledge, and strategy contributing to their understanding of integrated STEM education. If all of the opinions received from the teachers who participated in the process are summarized in general, teachers stated that course sessions that are aimed at integrating different disciplines during learning and teaching processes contributed to their knowledge and skills about;

- focusing on the process rather than the product,
- focusing on a problem rather than their disciplines,
- integrating disciplines rather than bringing them together,
- seeing the process from the student's point of view and the need to include computational thinking and algorithm as part of the process rather than a product.

Some of the teachers' views are as follows:

> *"Thanks to the interdisciplinary lesson approach, my awareness about different disciplines was raised; I realized that many outcomes can be achieved and that I needed more frequent contact with my colleagues in various disciplines."*

> *"We have learned once again that we need to work together with other disciplines. I think every subject is bound to be related to each other and should be considered when designing the curricula. I believe that with such a process, the planning process will be more successful."*

> *"Organizing a lot of information that will be a solution, making it meaningful, creating an algorithm for the operations we will do, and putting them in order (while preparing a lesson plan, thinking about what kind of algorithm we will want from the students and actually making an algorithm for this in our brains while doing this made me think of nested loops) have enabled permanent learning while understanding components."*

Most teachers indicated that they recognized that when addressing the interdisciplinary approach and planning the process with the 5E learning model, course sessions on the use of innovative methods such as inquiry-based learning, and mathematical modeling can be employed and can also effectively benefit from computational thinking and informatics.

> *"I had never done inquiry-based training before. I didn't know about modeling at all. I understood many things when these two approaches were combined in the lesson plan based on the 5E model we made recently. I am feeling more comfortable about how I can do my lessons with an interdisciplinary approach. I figured out how to incorporate other subjects into my lesson and use them truly integratively."*

> *"I can easily use the lesson plan and project we have prepared in my lesson at school. Each phase of the plan was written in detail as the group could exchange ideas, brainstorm, and make a joint decision... Using this plan in the lesson will facilitate time management and classroom management, and the permanent learning of the students will be positively affected."*

> *"It helped me to realize my deficiencies and faults in my knowledge of using the 5E model. I learned by exemplifying how I can use the three disciplines in an integrated way in my course design."*

Most of the teachers stated that they were pleased to work with the teachers from other disciplines and that at the end of the course process, they had improved in approaching learning and teaching processes from other subjects' points of view:

> *"Even though we were all from different subjects, no one withdrew into their own shell and worked by themselves. We were together at every step of the way; in this way, we worked in an integrated manner."*

> *"At first, each of us focused on our subjects. However, later on, we contributed to modeling and planning, such as a station approach. On the last day, we became a team and started noticing points that one another couldn't see."*

Teachers mostly made suggestions about forming groups to develop/improve the activity. Some of the teachers stated that creating at least one session only with teachers from the same discipline and constantly renewing groups except for the last 2 days that focus on designing lesson plans would significantly contribute to interaction and sharing. One of the teachers expressed the situation as follows:

> *"If science and mathematics teachers had thought about the same problem in their groups before the activity starting and if the groups were then united, we would have been able to observe the difference and what was discussed and planned in teachers' previous groups; teachers in different disciplines trying to combine each group's mutual thoughts could have made us see the difference in the interdisciplinary working principle a little more."*

Recommendations by researchers based on field notes

After completing TDC-II, an assessment was made on the teachers' opinions, observations of experts in the program, and field notes. It was observed that the workshop on artificial intelligence applications with an interdisciplinary approach exceeded the digital competencies of science and mathematics teachers. In addition, it was noted that teachers had difficulty identifying real-world problems that they will use while preparing their lesson plans collaboratively within the framework of the 5E model. It was determined that the one-time creation of groups for collaborative group work and the teachers working with the same groups from beginning to end limit the interaction with other teachers and the sharing of knowledge and experience.

Case Study III

Teachers' Opinions and Suggestions About TDC

Designing the learning and teaching process with the STEM education approach requires interdisciplinary knowledge and skills. Some of the views of the teachers who participated in TDC-III on interdisciplinary studies, interdisciplinary competencies, and the change and development in the program on their knowledge and understanding of collaborative working skills with teachers from different disciplines are as follows:

> *"Collaborative work was the best way to design a lesson plan covering three disciplines. Having a colleague from each subject revealed what we can and can't incorporate into the lesson plan that we dreamed of. Since 'the subject teachers know learning achievements very well, we realized our limitations and the topics we weren't knowledgeable about..."*

> *"I realized that it is possible to combine my achievements in my subject with the achievements of other disciplines and act together. I discovered that it is easier with other disciplines to plan activities for my students to solve problems in life and daily life."*

> *"We saw that it is impossible to solve a real-world problem through a single discipline; it should be solved by more than one discipline coming together. We saw that many unnecessary repetitions can be avoided when a problem is approached interdisciplinarity."*

Summarizing all the opinions of the teachers involved in the process, the teachers believe that when addressing the interdisciplinary approach and planning the process with the 5E learning model, course units can be used to apply innovative methods such as inquiry learning and modeling, and computational thinking and computer science can also be used effectively. Some teacher opinions supporting this situation are as follows:

> *"Seeing the importance of science and mathematics in developing common skills and integrating disciplines, it was an innovative output for me to observe where and how computing took place in the process."*

> *"I experienced the calculations I made only with paper and pencil in mathematics with real models and computer simulation. In this way, I integrated science and technology."*

As a result, it is understood that the teachers were satisfied with the practical activities in the program and returned from this activity with various gains. Teachers saw that they could work together with teachers from other disciplines by finding the opportunity to ensure interdisciplinary integration. It was revealed that group compliance is vital for effective collaboration and that collaboration is key to achieving interdisciplinary integration.

Some teachers made suggestions for extending the time to improve program activities. In addition, they emphasized the importance of providing preliminary information at the theoretical level to eliminate the difference in readiness among some teachers about the course. All of the teachers who took part in the interviews believed that educational resources, such as theoretical information and guidelines for program activities, should be supplied to them ahead of time. The following are some examples of this situation:

> *"First of all, it is a multi-step study that requires longer time to communicate with other subjects, understand the outputs, combine them with our outputs, and bring them together. Making an update on the duration may increase the validity of the products to be revealed."*

> *"In my opinion, we had too many shortcomings. I think the time given can be increased a little. In fact, the plan requested from us can be presented to us in the form of preliminary information before the theoretical course sessions are given. In this way, we can know the point we need to focus on from the beginning."*

Recommendations by researchers based on field notes

After completing TDC-III, an assessment was made on teachers' opinions, observations of experts in the program, and field notes. According to this assessment, experts and principal researchers consensus that more time should be allocated to the activities so that teachers can complete the activities in the program, placing theoretical activities at the beginning of the program and increasing the duration of course activities. In addition, an idea was put forward to organize online meeting activities that will allow teachers to get to know each other before the course for extraordinary periods, such as when the COVID-19 epidemic was experienced.

Comparison of Cases

This study compared three consecutive TDCs in pedagogical knowledge, technological knowledge, and strategy. Then, a portrait of the change and development of the programs over the years was trying to be drawn. The first TDC was designed around the needs that the authors identified and observed in their studies (Mumcu & Uslu, 2019; Uslu & Mumcu, 2020). TDC-II and TDC-III were redesigned based on the authors' research on teachers' expectations from a professional development program for integrated STEM education (Mumcu, Uslu, & Yıldız, 2022), the suggestions of the teachers who attended the first TDC, the observations made by the experts, and the field notes they took. Interviews with teachers showed an essential need for TDCs that address the integration of different disciplines and that teachers will collaborate with their colleagues from various fields.

As a result of the three TDCs, the point reached by the TDC designs in terms of technological knowledge, pedagogical knowledge, and strategy is shown in Figure 1.

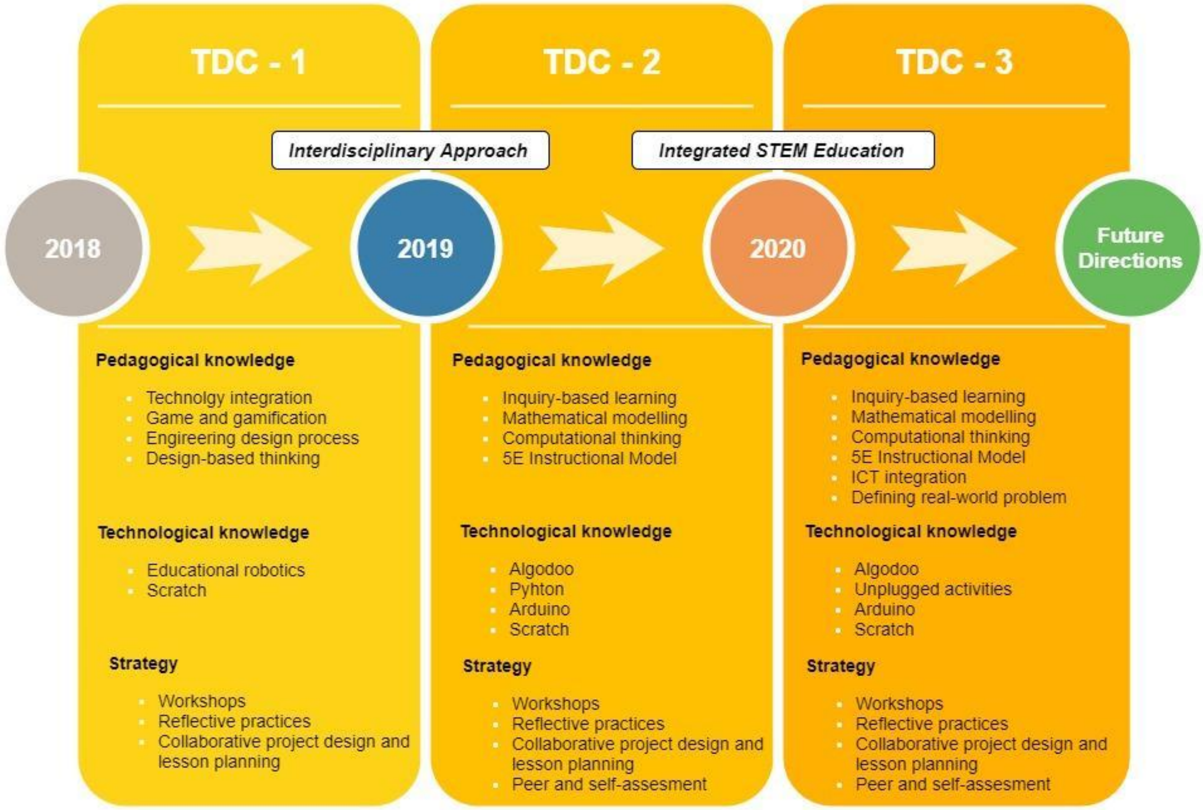

Figure 2. The change of TDCs over the years

Results and Discussion

This study examines the change of three consecutive TDCs in practice based on the needs emphasized in the literature for integrated STEM education. STEM education is based on collaboration. It distinguishes it from individual-based educational activities (Li et al., 2020a). This collaboration can occur in two situations, with other institutions and with teachers. Cooperation between schools and universities provides essential support in teachers' PD (Hamilton et al., 2021; Lehman et al., 2014). In this study, cooperation was ensured both between schools and universities and among teachers. Experts trained teachers who work actively in STEM disciplines, and teachers' PD was supported to transform theoretical knowledge into practice in schools.

The starting point of the first TDC is to nurture computer science teachers' integrated STEM teaching competencies technologically and pedagogically. However, the first TDC showed the necessity of interdisciplinary work to enhance integrated STEM education and the computation side of STEM education. For this reason, we decided to integrate science and mathematics education, which are the core disciplines of STEM, with computer science education; as of 2019, we changed the program's content. Mathematical modeling and inquiry-based learning were added to the content. Because modeling activities are based on real-world problems and require interdisciplinary associations, they are proper for integrated STEM education (Sevinç, 2019). Although the developed model is expressed with mathematical symbols and representations, it requires evaluating, processing, and blending of information from different disciplines, especially science and computer science. As inquiry-based learning emerges in science education, it may appear relevant only to this field, but it is not limited and occurs in mathematical or technological concepts (Thibaut et al., 2018). Inquiry-based learning is defined as one of the five fundamental principles of integrated STEM (Thibaut et al., 2019).

Science and mathematics are core disciplines of the STEM acronym. Besides, with the emergence of computational branches of sciences such as computational biology and astronomy, the sciences are becoming more computational (Ketelhut et al., 2020). In this respect, STEM education researchers recognize the importance of integrating computational thinking into the curriculum (Barr & Stephenson, 2011; Sengupta et al., 2013); however, computation at the K-12 level remains a particular field of study (Dickes et al., 2020; Arastoopour-Irgens et al., 2020). Computational thinking makes science and mathematics education more compatible with current professional practices in these fields (Weintrop et al., 2016). Shute et al. (2017) emphasize that STEM curricula should strengthen computational thinking. So, we also focused on the integration of computational thinking into STEM education.

Due to the nature of integrated STEM education, we included science teachers, mathematics teachers, and computer science teachers in TDC-II and TDC-III. The second TDC showed that this work could be done by integrating teachers' content knowledge from different disciplines with the products prepared by teachers in terms of interdisciplinary work and integrated STEM education. Integrated STEM learning activities should support students' integrating knowledge and skills from STEM disciplines as they tackle real-world problems, and this integration should be reflected in how students are assessed (Newhouse, 2017). The teacher needs to plan the learning-teaching process in detail. However, it has been seen that most of the teachers who stated that they did interdisciplinary practices could not design an interdisciplinary lesson, despite having a positive attitude towards it (An, 2017; Gürkan, 2019). The disadvantages of the second TDC were identifying real-world problems, the lack of response to the engineering approach for science and mathematics teachers, and the rigidity of the collaborative working strategy.

In the third TDC, we primarily focused on the ICT integration and the role and purpose of using "T"echnology in integrated STEM education. Then, we used the SDGs as a resource to identify a real-world problem that will be the subject of the learning and teaching process and attract the students' attention and curiosity. Thus, we worked on how teachers would determine the content that would combine different disciplines. Finally, we gave the teachers learning tasks to work collaboratively with teachers in their disciplines first and teachers from other disciplines later. Each program's primary and common point is to produce products that will guide teachers' in-class practices and increase pedagogical and technological competencies. At the end of each program, lesson plans were designed by the teachers through collaborative group work, and the prepared lesson plans were published as e-books. Ensuring a talented generation interested in STEM requires establishing teams of teachers working together with an integrated approach based on cross-curricular teaching and learning (Kurup et al., 2019). As a result, these programs encouraged teachers responsible for their lessons at school and who received teacher education on the single-discipline level to work collaboratively with their colleagues, focus on interdisciplinary education, and produce with teachers from different disciplines. TDCs demonstrated that integrated STEM education could be accomplished by integrating teachers' content knowledge from various disciplines. Becker and Park (2011) found in their meta-analysis study on the effects of integrative approaches on STEM subjects that students did better when they learned STEM in an integrated way.

As a collaboration with external stakeholders such as universities, collaboration among teachers is vital in STEM education for schools (Herro & Quigley, 2017). In addition to sharing the workload of planning and implementation, teachers, as a group who support each other (Asghar et al., 2012), recognize the importance of collaboration (Hamilton et al., 2021). Herro and Quigley (2017) stated that collaboration in STEM education-related to interdisciplinary teaching is necessary to understand its content, connect with experts, and enable discussions to overcome future challenges. Teachers' confidence, efficacy, and perceptions towards STEM education increase when they work together and harmonize their standards (Nadelson et al., 2013). There is a limited number of studies on teachers from different disciplines working collaboratively to create, implement and disseminate an integrated STEM curriculum (Balgopal, 2020). In light of the STEM studies conducted in Turkey, it is found that TDCs are insufficient in terms of integrated STEM education, learning activities, and measurement (Guenbatar & Tabar, 2019), and it is recommended to increase STEM and STEM -based instructional activities and expand the content and scope of TDCs (Eroğlu & Bektaş, 2016). The TDCs discussed in this study enable teachers from three disciplines to use each other's knowledge within the scope of integrated STEM education. In this respect, the following points were taken into consideration as the main characteristics of an effective interdisciplinary TDC in the study (Margot & Kettler, 2019; Asghar et al., 2012):

- Bringing together teachers from different disciplines, not based on a single discipline
- Developing teachers' skills in designing learning-teaching processes integrating disciplines and guiding their classroom practices
- Encouraging teachers to work in collaboration with other teachers
- Doing tasks allow teachers to interact interdisciplinary throughout the program

In short, teachers stated that they experienced a positive development in their knowledge and understanding due to the programs, increased their awareness by developing different perspectives, and nurtured each other by exchanging ideas with their colleagues. It was concluded that the teachers were willing to transfer their experiences in TDCs to in-class practice. Teachers also stated that they gained many achievements from the group work they participated in with their colleagues and intended to keep in touch. In addition, it was determined that TDC activities guide and contribute to teachers' graduate studies.

Conclusion & Implications

The study presents tips on STEM teacher development in terms of technology, pedagogy, and content dimensions. The fact that STEM education is process-oriented rather than product-oriented offers remarkable findings on integrating disciplines, the versatility of STEM pedagogy, and the role of technology. In addition, the common emphasis of all three TDCs is how vital collaboration, communication, and group cohesion among the teachers during the program is. It was found that group cohesion is vital for effective collaboration, and collaboration plays a crucial role in ensuring interdisciplinary integration. It was also found that teachers' expertise in their subjects is an essential factor in the collaborative working process.

With the study, the authors aimed to establish a link from practice to theory by examining how theoretical knowledge corresponds in practice in the light of integrated STEM education based on teacher education. This study is expected to shed light on studies focusing on the PD of teachers for integrated STEM education. Different collaboration methods and strategies to increase group cohesion adopted in the TDCs for integrated STEM education in future studies will contribute significantly to the literature. Teachers' taking an initial STEM education is an essential factor; there is also a need for future studies to be carried out within the scope of the sustainability of PD. Among the authors ' aims are organizing studies that support sustainable PD for teachers who participated in the program.

Limitations

All Case 1 participants are computer science teachers, while Case 2 and 3 participants are computer science, science, and mathematics teachers. Authors took part in all TDCs. However, due to many modules and diverse content, experts working as faculty members at universities took part in some modules. Since each TDC is designed as a training camp, the training period is limited to 1 week.

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Author (s) Contribution Rate

FM, NAU and BY contributed equally to designing of and conducting the research and collecting the data. FM and NAU analyzed the data and FM and FO created the figures. FM carried out the literature review, wrote and prepared the manuscript. NAU provided insight and editing of the manuscript. FM and FO contributed equally the discussion and conclusion parts of the manuscript. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Approval

Written informed consent was obtained from all participants before the study. The study was conducted by considering other ethical principles.

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