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Science Teachers' Technological Pedagogical Content Knowledge: An Explanatory Sequential Design

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Abstract

This explanatory sequential mixed-method study aims to investigate science teachers' technological pedagogical content knowledge (TPACK) competencies and determines their TPACK indicators based on the TPACK-Deep framework. The participants were 136 science teachers (85 females and 51 males) from a small city where 232 science teachers work. Three of them with different TPACK competencies participated in the qualitative part to observe actual classrooms. Data sources were the TPACK-Deep scale, classroom observations, video recordings of the instruction, and semi-structured interviews. For the quantitative part, data were analyzed by descriptive statistics using the IBM SPSS 26.0 version. In addition, the qualitative data were analyzed based on deductive and inductive content analyses. Deductive analysis was made using the "Table of Indicators and Competencies of Technopedagogical Education". The findings showed that science teachers' TPACK competency was high. Science teachers with higher TPACK competency scores showed a high number of classroom indicators whereas teachers with low TPACK competency demonstrated a lower number of classroom indicators. Although the teacher with a high TPACK competency showed more TPACK indicators than medium and low levels, their overall number of TPACK indicators was similar and low. Therefore, the current study also revealed that science teachers' self-assessment scores do not fit their TPACK in action indicators.

Introduction

According to the International Society for Technology in Education (ISTE) (2017), teachers are expected to use technological tools and digital resources to support students' learning. Therefore, their knowledge and competencies regarding these sources are of vital importance (Mishra et al., 2023). This was evidenced when the sudden COVID-19 outbreak obliged teachers to teach online by finding different solutions for distance learning at all school levels. Although Shulman (1987) conceptualized teachers' knowledge as Pedagogical Content Knowledge (PCK) by blending pedagogy and content, Mishra and Koehler (2006) added a technology dimension to PCK and conceptualized it as a Technological Pedagogical Content Knowledge (TPACK). Adding a new knowledge domain has resulted in a more complex framework (Graham, 2011; Kimmons, 2015; Sang et al., 2016; Schmid et al., 2020). However, the TPACK framework has received several different points of view, resulting in the emergence of several different models.

Integrative and Transformative TPACK Models

The integrative model represents that TPACK is composed of seven domains and that teachers' TPACK is improved when any of the knowledge domains are developed (Mishra & Koehler, 2006). In other words, each domain makes a direct contribution to the overall TPACK growth. Thus, in the integrative models, individual TPACK domains are researched separately. In this sense, Jimoyiannis (2010) investigated science teachers' Technological Pedagogical Science Knowledge (TPASK) by focusing on individual knowledge domains. Jang and Tsai (2012) also researched mathematics and science teachers' TPACK, considering contextual knowledge. In addition, Lin et al. (2013) investigated science teachers' perceptions of TPACK by considering seven TPACK components separately.

On the other hand, the discussion about the integrative model, demarcation of the domains (Archambault & Barnett, 2010), and "fuzzy boundaries" between TPACK constructs (Cox & Graham, 2009; Schmid et al., 2024) led to the transformation of a transformative model of TPACK, which accepts TPACK as a "unique type of knowledge" (Angeli & Valadines, 2009, p.154). The model supports the idea that adding individual components cannot adequately explain teachers' TPACK. Instead, it is best understood as a framework that emphasizes combining and integrating all its dimensions to achieve teacher knowledge. It includes knowledge about the content, pedagogy, students, context, and tools and how technology can effectively transform them (Angeli & Valadines, 2009). In other words, teachers' TPACK is transformed when teachers design and implement instruction in a particular topic with the effective use of technology (Koehler & Mishra, 2009; Schmidt et al., 2009). Based on this view, Jang and Chen (2010) developed the 'TPACK Comprehension, Observation, Practice, Reflection (TPACK-COPR)' model for preservice science teachers' science-specific TPACK. In a different example, Yeh et al. (2014) proposed the TPACK-Practical (TPACK-P) model by considering science teachers' TPACK-in-action behaviors by focusing on eight dimensions and indicators in practical teaching, curriculum design, subject content, learners, and assessment.

Although different subject-specific TPACK models have developed in science education, either integrative or transformative, the actual practices of science teachers' TPACK need to be researched because how teachers transform their knowledge into actions is not well known. Moreover, the contextual knowledge (CxK) that encircles the TPACK is an important domain of the TPACK framework (Mishra, 2019). However, CxK is not generally investigated in the past research (Rosenberg & Koehler, 2015). According to Koehler and Mishra (2009), the instruction should be designed for the specific subject and learning context. For that reason, to understand teachers' TPACK, on-site observations would give enhanced information about how teachers transform their TPACK. Also, there is a gap between science teachers' knowledge of TPACK and its application (Jen et al., 2016), but further investigations are needed for specific contexts and topics.

According to Voogt et al. (2013), detailed research is required to understand the complicated relationships between TPACK and teachers' practices because there are discrepancies between science teachers' self-assessment and actual teaching (Backfisch et al., 2020; Chai et al., 2016; Jen et al., 2016). Therefore, this research was conducted for several reasons: (1) teachers' technology integration practices differ according to the subject matter (Koehler & Mishra, 2009) and require topic-specific investigations, (2) since self-assessment surveys mainly focus on technology and pedagogy dimensions, highlighting the need for content-specific examinations (Chai et al., 2013; Fabian et al., 2024; Voogt et al., 2013), thus it is needed to investigate teachers' TPACK on a particular domain in a specific topic; (3) TPACK is "idiosyncratic" (Cox, 2008, p. 47), requiring analysis in more specific; and (4) linking self-reported scores with indicators derived from observed teachers' practical mastery in instructional artifacts and classroom applications (Jen et al., 2016, p. 47) provides a more comprehensive understanding of teachers' TPACK-in-action. Consequently, this study examined science teachers' TPACK through self-reported data and observations of their classroom practices."

The Present Study

The primary purpose of the current study was to determine science teachers' TPACK competencies and investigate their TPACK indicators in their instruction on the topic of meiosis. Therefore, the aim of the current study is twofold: to investigate science teachers' (1) TPACK competency levels and (2) TPACK indicators in the meiosis topic. On these aims, the meiosis topic was selected due to (1) the lack of topic-specific investigations of teachers' TPACK in meiosis, (2) the topic is a prerequisite for future topics like genetics and reproduction (Atilboz, 2004), (3) different misconceptions exist on that topic (Atilboz, 2004; Gunes & Gunes, 2005; Sen et al., 2018), (4) the meiosis is abstract and complex to understand (Angeli & Valanides, 2009; Atilboz, 2004; Gunes & Gunes, 2005; Lewis et al., 2000), and (5) it is hard to teach with traditional methods of instruction (Angeli & Valanides, 2009). Within this scope, the present study used the TPACK-Deep scale (Kabakci-Yurdakul et al., 2012), which is a reliable tool to measure teachers' TPACK. Also, it is based on the transformative model, which accepts that teachers' knowledge transforms in practice and focuses on teachers' lesson planning. In this regard, the research questions were as follows:

1) What are the science teachers' TPACK proficiency levels in a small city according to the TPACK-Deep scale?
2) What are the indicators of science teachers' TPACK regarding the "meiosis" topic considering TPACK-Deep factors?
3) In what ways do the teachers' interview data and classroom teaching help to explain their proficiency scores about TPACK-Deep?

Material and Methods

The study was an explanatory sequential mixed-method design with quantitative and qualitative parts (Creswell & Plano-Clark, 2017). Firstly, the quantitative data were collected and analyzed. Then, qualitative data were collected and analyzed. Finally, quantitative and qualitative analyses were integrated and interpreted (see Figure 1).

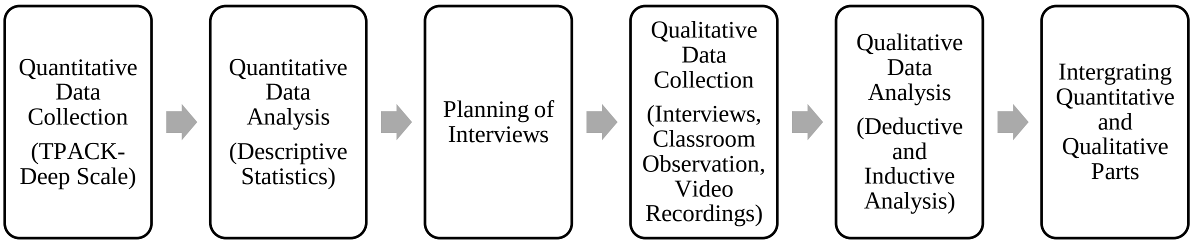

Figure 1. The Research Design

The Context, Sample, and Participants

The study was conducted in a context where classrooms were enriched with smart boards between 2010 and 2015. Although inequalities exist in terms of socioeconomic status and population distribution, the curriculum is centralized. The data were collected from a small city of Turkey, in a rural area close to Turkey's capital, just right before the COVID-19 pandemic. Although the observed classrooms had smart boards and Internet connection, students lacked personal electronic devices such as tablets in school settings. Likewise, the schools have science laboratories lacking laboratory materials.

The population consisted of 232 science teachers working in public middle schools (grades 5-8) in the small city where the data were collected. The sample for this study was selected using a convenience sampling strategy and included 136 science teachers (85 females and 51 males). Firstly, the teachers' TPACK competencies were determined (as high, medium, and low) based on the criteria suggested by Kabakci-Yurdakul et al. (2012). Then, three science teachers with varying TPACK competency levels were purposively selected as research participants for the qualitative part of the study. The selection process also considered participant characteristics, including a balance of genders and the availability of technology in their schools.

Data Collection Tools

The current study provides data triangulation with self-reported data with classroom observations, video recordings, and semi-structured interviews to understand science teachers' TPACK by explaining how and why they integrate technology into their instruction. Quantitative data were collected through the TPACK-Deep scale. Moreover, qualitative data were collected through classroom observations, video recordings, and pre-and post-semi-structured interviews.

TPACK-Deep Scale

In this study, an online version of the TPACK-Deep scale, developed by Kabakci-Yurdakul et al. (2012), was used. The TPACK-Deep is a five-point Likert type used to define the TPACK competency levels of pre and in-service teachers. Moreover, it consisted of 33 items with four factors: design, exertion, proficiency, and ethics. Table 1 represents the TPACK-Deep factors, example items, and Cronbach's alpha reliabilities. The data from this study indicate that the scale is reliable. (Pallant, 2007).

Table 1. TPACK-Deep Factors, Sample Items, and Reliability Coefficients

TPACK-Deep factors	*Items*	*Sample item*	*Cronbach's alpha coefficients*	
			Kabakci-Yurdakul et al., 2012	*Present study*
Design	1-10	I can use technology to develop activities based on students' needs to enrich the teaching and learning process.	0.92	0.94
Exertion	11-22	I can apply instructional approaches and methods appropriate to individual differences with the help of technology.	0.91	0.94
Ethics	23-28	I can use technology in every phase of the teaching and learning process by considering copyright issues.	0.86	0.91
Proficiency	29-33	I can troubleshoot any kind of problem that may occur while using technology in any phase of the teaching-learning process.	0.85	0.87

Interviews

Pre-interviews. The primary purpose of the pre-interviews was to learn teachers' planning for the lesson. Based on this, a semi-structured interview protocol was prepared considering the TPACK-Deep factors: design, exertion, proficiency, and ethics. Then, the protocol was finalized by an expert in the TPACK. Pre-interviews lasted 30 minutes on average. Sample questions from the pre-interview can be seen in Table 2.

Post-interviews. Post-interviews aimed to clarify what teachers did and did not do in their lessons. Questions were formed after analyzing each pre-interview and observation of the instruction. The interviews lasted 30 minutes on average. Sample questions from the post-interview can be seen in Table 2.

Table 2. Sample Questions from Interviews

Data Collection	**Number of questions**	**Sample questions**
Pre-interview	14 questions	*What factors do you pay attention to while planning today's lesson? (Probing: curriculum objectives, subject content, knowledge of the students, and physical conditions).*
Post-interview	6 questions	*How could you integrate technology into your instruction more? (Probing: Teaching methods, strategies, techniques, students' prior knowledge, possible misconceptions).*

Classroom Observation and Video Recordings

The purpose of the classroom observation and video recordings was to observe science teachers' practices and whether these practices show consistency with their survey results. In other words, they are used to explain the quantitative results. The data from the purposively selected participants with different TPACK competency levels were collected in one lesson hour on the meiosis topic.

Data Analysis

Quantitative Part

Quantitative data were analyzed by using descriptive statistics. The total score of the participants in the TPACK-Deep scale indicated their overall TPACK competency levels. The criteria were set by Kabakci-Yurdakul et al. (2012) as, scores lower than 95 are "low," 96-130 are "medium," and higher than 131 are "high".

Qualitative Part

The "Table of Indicators and Competencies of Technopedagogical Education" developed by Kabakci-Yurdakul et al. (2012) was used to determine teachers' competencies. Since it was formed according to factors of the TPACK-Deep, data were analyzed considering these factors. Two researchers, one expert in TPACK, coded the pre- and post-interviews and video data independently. Deductive and inductive content analyses were conducted (Miles et al., 2018). Deductive analysis was made because researchers used the TPACK-Deep framework. Inductive analysis was also conducted to find possible additional categories. Then, the analysis of two researchers' were compared. This strategy also decreased the potential bias for single-person analysis (Patton, 2002). To determine inter-rater reliability, the percent agreement method was used (Cohen, 1960), and 87% agreement was found. Further information about data collection and analysis can be found in the master thesis of the first author (Tanrisevdi, 2021).

Results

Science Teachers' TPACK Competencies

A descriptive analysis showed that science teachers' scores implied high TPACK levels (M= 132.32, SD= 17.17). Moreover, Table 3 shows science teachers' mean scores for each factor.

Table 3. Descriptive Analysis of Science Teachers' TPACK Scores according to the TPACK-Deep Scale

TPACK-Deep factors	***Items***	***Mean scores***	***Competency levels***
Design	1-10	3.91	High
Exertion	11-22	4.08	High
Ethics	23-28	4.24	High
Proficiency	29-33	3.75	High

The results showed that science teachers had the highest proficiency regarding ethical issues while integrating technology into their instruction, such as respecting access rights, privacy, and security issues (ethics factor). Also, they had lower competency in the content and pedagogy and solving possible problems (proficiency factor).

Science Teachers' TPACK Indicators

The Table of Indicators and Competencies of Technopedagogical Education (Kabakci-Yurdakul et al., 2012) included six competency areas, 20 competencies, and 120 performance indicators under the four factors of TPACK-Deep**.** To investigate science teachers' TPACK indicators in the meiosis topic, participants were selected according to their different TPACK-Deep levels. *Luke* had a high number of indicators in the exertion factor, which implies that highly competent while implementing technology-enhanced lessons in meiosis (see Table 4). Also, *Albert* had the highest number of indicators in the design factor, showing that he felt competent while designing instruction using technology. However, *Albert* considered himself less competent in the proficiency dimension, implying he has trouble with technology and solving technology-related problems in the lessons. On the contrary, *Nancy* had the lowest number of indicators in the design factor. In other words, she felt less competent in designing technology-integrated lessons. In the following parts, the analysis of participants' TPACK indicators was reported according to TPACK-Deep factors.

Table 4. The number of Indicators Observed for the Qualitative Part according to TPACK-Deep Factors

	Design	***Exertion***	***Ethics***	***Proficiency***	***Total***
Luke (High Level)	8	12	10	3	33
Albert (Medium Level)	8	6	6	4	24
Nancy (Low Level)	3	5	6	4	18

Design

Analyzing existing situations before teaching. Before teaching meiosis, *Luke* and *Albert* expressed that they analyzed the technology requirement according to the topic and the student's needs. Since teachers had limited opportunities in terms of technology, they analyzed the requirements in a more specific way. Namely, the updated curriculum, subject, and students' learning styles were considered while selecting technologies. As a result, they decided on technological materials to be used in the lesson. In this regard, *Luke* expressed:

> *In previous years, meiosis was in the 8th-grade curriculum. However, the topic is in 7th grade now and is complicated. Considering my students' needs, I will use animation in my lesson to make the topic concrete. Therefore, I need a computer and internet connection (Pre-interview).*

Determining appropriate methods, techniques, and technologies to be used in teaching. While determining technologies, techniques, and methods, the nature of the subject influenced participants' decisions. Since meiosis is abstract, they considered concretization of the topic. For example, *Albert* mentioned the nature of the topic and students' needs while determining technologies. Different from *Luke*, *Albert* mentioned time management and student's motivation for determining technologies. *Albert* expressed that:

> *I decided on methods and technologies based on the subject and my students' needs. For example, I will use the Antropi Teach program because it will save my lesson time. I could draw meiosis phases on the blackboard, but it would take my lesson time (Pre-interview).*

Similarly, *Nancy* stated that technologies must be compatible with the curriculum. *Nancy* said:

> *I will use technology to concretize the subject. In addition, it should be compatible with the curriculum. (…) Therefore, I selected a video that covers 7th-grade objectives (Pre-interview).*

The answers imply that teachers mainly mentioned determining technologies rather than determining appropriate methods for their instructions.

Preparing suitable environment, activities, materials, and measurement tools for teaching. While preparing activities and materials, teachers used accessible and valuable technologies, including smartboards and computers, which have already existed in their schools. Moreover, *Luke* explained how he benefited from technology in preparing his instruction. Regarding this, he stated:

> *As you know, the curriculum has changed. Thus, I use technology to follow this change. For example, I search and select updated animation for meiosis. (Pre-interview).*

Planning for teaching. Lesson planning includes the use of technology while planning the instruction. For example, using searching strategies to access resources and using technology to create a lesson plan to gain knowledge and skills were defined as performance indicators for this competency. In this respect, *Luke* mentioned:

> *When planning my teaching, I always use my personal computer and specific websites. To illustrate, for the meiosis subject, I looked for animations, videos, and online quizzes in digital learning portals (Pre-interview).*

Albert also reported:

> *For the meiosis topic, I use an educational portal in my lesson. Before the lesson, I prepare visuals, including phases of meiosis, on my personal computer (Pre-interview).*

Moreover, *Nancy* reported that if students' achievement levels and readiness differ, she can revise the lesson plan. Despite having different purposes, teachers used personal computers, different technological resources, and tools during instructional planning.

Exertion

Practicing the teaching. To guide students on the effective use of technology and support student motivation, *Luke* entered a classroom with a personal computer. In this respect, *Luke* stated:

> *I want to be a model for my students to use technology. In other words, I want to show how to use technology purposefully. I use different technological resources like videos and animations to broaden my students' vision. I believe they are motivated when I enter the classroom with my personal computer (Pre-interview).*

It was observed that *Luke* used animation to review mitosis, which is a prerequisite for meiosis. This animation included visual representations and transitions of phases of mitosis. While reviewing, *Luke* stopped the animation and asked questions to different students. Then, he used a blackboard to draw phases of meiosis and gave information about each phase. Also, *Luke* mentioned the purposes of meiosis, including genetic variations and maintaining a constant number of chromosomes. Then, he reviewed meiosis phases by using animation. While he was covering meiosis on the smartboard, he stopped the animation and asked about similarities and differences between mitosis and meiosis by posing questions to different students. Additionally, he stated that if the students have personal tablets or telephones, he will use virtual reality programs to make the topic concrete.

On the other hand, *Albert* reviewed the topic of mitosis by questioning. Also, he drew the first and last phases of mitosis for a diploid (2n) cell on the blackboard. Then, he moved on to meiosis and stated its importance. Rather than drawing each phase of meiosis, he used a program that included meiosis phases. By comparing each phase with mitosis, he organized meiosis phases on the smartboard. For reinforcement, he also used a video from a digital learning portal. Considering technologies that he used during instruction, *Albert* stated:

> *Antropi is a valuable program because I can show different phases with colored visuals interactively. Also, I will use a video from a digital learning portal to show the phases of meiosis in 3D. For the assessment, I will use a matching game presented in the digital learning portal. Students will solve questions individually using a smartboard (Pre-interview).*

Similar to *Luke* and *Albert*, *Nancy* reviewed mitosis at the beginning of the lesson. While she asked purposes and significance of mitosis, she drew phases on the blackboard and wrote information regarding each phase. Then, she showed an animation without asking questions. For the meiosis, *Nancy* showed a video from a digital learning portal that was related to the phases of meiosis. Throughout the video, she stopped several times and asked questions to students. While evaluating her teaching about the use of technology, *Nancy* criticized her instruction. Additionally, she made a self-evaluation about the assessment. *Nancy* stated:

> *For the assessment part, rather than using paper and pencil tests, I could use a digital learning portal (Post-interview).*

Data sources implied that observed technology integration processes and practices were dominantly teacher-centered. Students participated in the lesson process only by questioning. On the other hand, participants mostly used technology for reinforcement rather than teaching new content with technology. Although designing instruction is different, teachers demonstrated similar patterns and indicators despite their different TPACK levels.

Ethics

Respecting access rights in the use of technology. Providing equal access to technological resources is a significant indicator of the ethics factor. Since students did not have personal technological devices in the observed lessons, teachers provided equal access to the existing technologies. For example, *Albert* used a technology-based activity from a *digital learning portal*. Students answered matching, true-false, and completion activities using the smartboard individually. Also, *Luke* commented on access rights from a broader perspective. In this regard, he gave the following explanations in the interview:

> *I use technology in all science classrooms. I mean, I use the same animation for different classrooms. Also, I try to give equal rights to speech while using technology (Pre-interview).*

Respecting technology-based intellectual property rights. Intellectual property rights are related to copyright and ethical use of digital resources. Based on the definition, teachers reported that they were careful about the copyrights of the resources. According to participants, being open to the public was the most important factor for using technological resources. In this regard, *Albert* stated:

> *A digital learning portal is open for teachers. Therefore, I use it for my lesson. If restrictions exist or the developer does not give permission, I will not use this source (Pre-interview).*

Similarly, *Nancy* reported:

> *Since the Ministry of National Education (MoNE) recommends a learning portal, I use it without getting permission. It is open to teachers (Post-interview).*

Respecting the accuracy of technology-based information. Teachers were attentive to transferring accurate information to students. In this sense, they reported reviewing technologies before teaching, especially to avoid misconceptions. *Albert* reported:

> *Last night, I opened a video related to meiosis. In this video, it was said that meiosis happens in gametes. However, it was a misconception because it occurs in germ cells. Therefore, I did not use this video (Pre-interview).*

Albert and *Luke* pointed out trustworthy websites with extensions like .edu and .gov. Although teachers have different TPACK-Deep scores and competency levels, there is a consensus among them on how to transfer correct technology-based information. According to teachers, these websites included trustable information. *Luke* stated:

> *While planning my instruction, I try to use reliable technological sources. There exist leading trustable websites. Nevertheless, if I use different sources, I research and investigate the accuracy of information (Pre-interview).*

Related to transferring correct information, *Nancy* stated:

> *Accuracy of information is the most important part of teaching. I consider each word when I teach. In addition, it is important to have correct information in instructional materials. Therefore, I use trustworthy technological sources suggested by the MoNE (Post-interview).*

Paying attention to the ethics of teaching. As an indicator, ethics of teaching include enabling students to use technologies ergonomically. Karwowski (2005) classified ergonomics as physical, cognitive, and organizational. In the current study, using technologies ergonomically is considered physical and cognitive. *Albert* selected suitable technological resources according to students' age, ability, and lesson objectives, considering cognitive ergonomics. Also, physical ergonomics has already been supported for observed classroom context because smartboards are fixed according to students' physical conditions.

Proficiency

Following up-to-date information about the content. Luke reported that to be prepared for the lesson and students' questions, he searched for additional information and materials. *Luke* said:

> *While preparing for the lesson, I pay attention to my knowledge about meiosis. I consider whether I can answer students' extreme questions. (…) I follow some reliable websites that include extra information and materials. In that way, I keep myself updated (Pre-interview).*

Solving technology-related problems. In the case of technology-related problems, traditional teaching was considered. In this regard, *Albert* stated:

> *The digital learning portal has opened slowly in recent times. In these cases, I do not use technology. Of course, I have a plan B. I will use the blackboard for the writing and drawing phases of meiosis (Pre-interview).*

In contrast, *Nancy* prepared alternative activities if there were connection problems. As a solution, *Nancy* reported:

> *Disconnection is a big problem for us. In addition, the smartboard may freeze. When it freezes, you cannot do anything. (…) If I have technological problems in meiosis, I have an alternative activity. We have plates, colorful straws, rope, and so on. Using the analogy method, I can teach meiosis with these materials (Pre-interview).*

In their lessons, teachers faced some problems. For example, *Luke* could not initially connect his personal computer with the smartboard. He used additional wire to solve this problem. On the other hand, *Nancy* had trouble opening her account in EBA. To solve this problem, she used an alternative sign-in option.

Solving problems related to content knowledge. In the interviews, teachers mentioned students' misconceptions about meiosis. It was reported that students might think: (1) meiosis happens in gametes, (2) separation of sister chromatids happens in meiosis-I. However, only *Albert* reported how to overcome misconceptions:

> *My students are confused about the separation of sister chromatids and homolog chromosomes. (…) To overcome this misconception, I integrate a digital learning tool into my instruction for visual support. In this program, I can easily show the differences between sister chromatids and homolog chromosomes (Pre-interview).*

Discussion and Conclusion

The present study aimed to determine science teachers' TPACK competencies and investigate their TPACK indicators in their instruction on meiosis. Therefore, the aim was twofold: (1) to determine middle school science teachers' TPACK competency levels, and (2) to investigate their TPACK indicators on the meiosis topic in the actual classroom setting. The study revealed that science teachers' TPACK competency levels were high based on their self-reports. However, when actual classroom indicators were examined, it became clear that, despite varying levels of TPACK (low, medium, and high) among the participants, all teachers demonstrated a limited number of TPACK indicators. In other words, there was a gap between teachers' knowledge and their implementation of the meiosis topic in a given context.

It was revealed that science teachers' TPACK competency levels were high. Several studies have reported similar results (Sari et al., 2016; Bagdiken & Akgunduz, 2018; Coklar & Ozbek, 2017; Mai & Hamzah, 2016). The high

TPACK scores on the scale may be due to teachers' teacher-centered beliefs. Angeli and Valanides (2009) stated that if teachers believe in teacher-centered instruction, the teacher will integrate technology that is mostly teacher-directed. In other words, their self-efficacy will be high for integrating technology in the self-report instruments, resulting in higher levels of TPACK. Another probable explanation for finding higher levels of TPACK may be due to technology-related PD programs in which they participated. Teachers participating in technology-related PD programs have higher TPACK levels (Alayyar et al., 2011; Graham et al., 2009; Kafyulilo et al., 2014; Lachner et al., 2021). Participants of this study stated that they actively use technology in their classrooms, especially computers and smartboards. Thus, their higher TPACK levels may be due to teachers' daily use of technology.

However, the results of this research are incompatible with some of the previous studies considering the level of TPACK (Bingimlas, 2018; Yeh et al., 2015). Different research contexts may result in conflicting results. Since, in the given context, the science curriculum relies on constructivism and student-centered philosophy, teachers might see themselves as having constructivist epistemologies while adopting technologies. That is, they may have felt themselves more competent. Furthermore, the nature of different TPACK scales may cause variation. The current study utilized the transformative scale, which has no particular items regarding different TPACK domains as the integrative TPACK view suggested. Since the items are blended with the domains of TPACK, participants who feel confident in classroom management, even if they lack competency in technology, may rate themselves higher. Also, in the TPACK-Deep scale, the items do not contain the specific names of the technologies. When participants rated themselves, one may think of common technologies like computers or more complex ones like Arduino. Therefore, teachers who assume these technologies are basic may score themselves higher. As a result, overall higher ratings may have caused higher levels of TPACK.

On the other hand, according to TPACK-deep factors, teachers' TPACK indicators on the meiosis topic in the actual classroom setting are limited. In other words, the results showed that the self-reported TPACK-Deep scores and indicators have inconsistencies. Although participants' TPACK levels differed in low, medium, and high, their actual teaching indicators and TPACK competencies showed similarities. In other words, there is a gap between teachers' knowledge and their implementation (Yeh et al., 2017). To illustrate, teachers' self-reports were student-centered in the interviews, yet their classroom indicators showed they were teacher-centered and transmitted knowledge. There is a gap between their self-assessment and actual behavior in a given context. Similar inconsistencies were also found in the literature. For example, teachers' knowledge levels were higher than their actual application levels (Jen et al., 2016) and different from their actual teaching (Yeh et al., 2015). Since self-report data does not directly reflect teachers' technology integration experiences (Koh & Chai, 2014), the contradiction might be observed because teachers scored themselves over or underestimated on the scale. Another reason can be the lack of practical experience in technology integration. In the study context, even if teachers had smartboards in their classrooms, they were not given any practice in integrating the technology into science classes. They are given obligatory professional development programs. However, these are not related to transforming the knowledge into practice. To improve practice, teachers should experience how technologies can be integrated into science lessons (Jen et al., 2016). The more the teachers integrate technology and become experienced, the greater their proficiency levels become (Jen et al., 2016; Tondeur et al., 2020). In addition, Tsai and Chai (2012) proposed third-order barriers, such as "teachers' lack of design thinking", that affect their actual teaching. This is related to the context of the study and the policy that cannot provide teachers with opportunities to develop themselves and integrate technologies effectively. Also, assessment was found to be a theme in previous studies (Ocak & Baran, 2019; Yeh et al., 2015), yet in the current research, there were not any indicators regarding assessment. This may be due to teachers focusing only on “teaching” and trying to show how they integrate technology into the teaching and ignoring assessment which is also part of the teaching.

Recommendations

This study provides a perspective on science teachers' TPACK practices, particularly by identifying differences between self-assessment scores and science teachers’ actual classroom behaviors. These findings underscore redesigning professional development programs to include practical training components. Such efforts can bridge the gap between theoretical knowledge and its practical application in educational settings. One of the primary strengths of this study is its comprehensive analysis of TPACK practices, achieved through the integration of both quantitative and qualitative data. However, the generalizability of the findings is limited by the research’s specific geographic and contextual focus. The study was limited to middle school science teachers working in a public school in a small province. Future research could expand to include teachers from private schools with access to more advanced technological resources. Furthermore, according to Porras-Hernández and Salinas-Amescua (2013), four key contextual implications influence teaching: "the students' characteristics, classroom and institutional conditions for learning, situated teaching activities, and teachers' epistemological beliefs" (p. 226). These contextual dimensions may contribute to variations in teaching practices, suggesting that replicating this study in different contexts would be beneficial. Additionally, the qualitative part of the present study was limited to lessons on the meiosis topic. Different topics and grade levels may give insights into science teachers’ technology integration practices. Extending the observation period to gain a more comprehensive understanding of these practices is also recommended. While classroom observations were triangulated with interviews, analyzing teachers’ lesson plans could further enhance the triangulation process. Fraenkel et al. (2012) stated that convenience sampling limits generalizability; thus, detailed descriptions of the sample are suggested if random sampling is not applicable. For that reason, the researchers collected detailed information from survey participants. Moreover, increasing the sample size is strongly recommended for future research.

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Ethical Statement

In this research, the ethics committee approval notification document containing the eligibility decision for the research was received from the Middle East Technical University Human Research Ethics Committee (No:

193ODTU2020) and the Ministry of National Education (No: 81576613/605.01/305505). All ethical procedures were followed during and after completing the research.

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