MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2025, 21(1), em2570
ISSN:1305-8223 (online)
OPEN ACCESS Research Paper https://doi.org/10.29333/ejmste/15896

Empowering STEM teachers with TPACK: Insights from the DECODE online professional development program

Bevo Wahono [1*], Slamet Hariyadi [1], Agung Wijaya Subiantoro [2], Jose Arturo Molina Bravo [3], Marison Sudianto Manalu [4]

[1] Faculty of Teacher Training and Education, University of Jember, Jember, INDONESIA
[2] Faculty of Mathematics and Natural Sciences, Yogyakarta State University, Sleman, INDONESIA
[3] Facultad de Ciencias de la Educación, Universidad Pedagógica y Tecnológica de Colombia, Tunja, COLOMBIA
[4] Graduate Institute of Science Education, National Taiwan Normal University, Taipei, TAIWAN

Received 30 September 2024 ▪ Accepted 13 January 2025

Abstract

This study was carried out to analyze an online science, technology, engineering, and mathematics (STEM) teachers' professional development using the DEmonstration, CO-train/design/teach, DEbrief (DECODE) model to empower teachers in refining technological pedagogical content knowledge (TPACK) skills. The model was performed due to the focus on STEM education as well as the ongoing challenges posed by the virtual environment era. The online DECODE model is mainly based on virtual lectures in combination with hard copies of instructors' manuals, forming a blended training model. Therefore, the model empowered teachers to refine TPACK skills through familiarization with various software technologies and enhancing proficiency in instructional design. A total of ninety-one teachers from diverse educational settings, including urban, suburban, and rural schools, actively participated in a comprehensive 72-hour study. A willingness to engage in similar STEM-TPD sessions in the future was expressed after the analysis of open-ended questions. Furthermore, the paired sample t-test results showed a significant difference in TPACK ability before and after the training ($t = 4.21$; $p = <.001$; $d = .82$). The results showed that online teachers had increased the understanding and ability of TPACK after participating in online STEM-TPD workshop. Therefore, STEM-TPD with the DECODE model was essential to preserving teaching quality in the virtual and digital age.

Keywords: cloud classroom, DECODE model, professional development, STEM, TPACK

INTRODUCTION

Science, technology, engineering, and mathematics (STEM) teachers can help advance quality human resources in the 21st century era. Therefore, STEM teachers must have competence, knowledge, skills, and professionalism standards (Even-Zahav et al., 2022). In addition, a professional STEM teacher must be able to apply technology in delivering learning materials (Chiu et al., 2021). Fundamentally, other education components (e.g., teaching process, curriculum, etc.) are also affected and can be supported through workshops, competency testing, training, teacher performance evaluation, and professional development (Perry & Booth, 2021; Wahono et al., 2021). One of the professional development activities for STEM teachers that can be followed in the post-pandemic era is online teacher professional development (TPD).

Concerning the challenges to overcome in the virtual and digital age (e.g., massive and fast information), most activities, such as the learning process, collection of assignments, and student-teacher/teacher-teacher interactions inside or outside the school academic environment, including teacher's workshop, are conducted online. Those online activities provide many benefits, such as a flexible learning mode (Culduz, 2024). Accordingly, the online TPD program is a solution to improve the quality of STEM teacher education in

✉ bevo.fkip@unej.ac.id **(*Correspondence)** ✉ s.hariyadi.fkip@unej.ac.id ✉ agung_wijaya@uny.ac.id
✉ jose.molina05@uptc.edu.co ✉ marisongoodjob@gmail.com

Contribution to the literature

- This study contributes to the literature by demonstrating the DECODE model's effectiveness in enhancing STEM teachers' TPACK skills in an online TPD setting. The statistically significant improvement in teachers' technological pedagogical content knowledge (TPACK) supports the idea that structured, interactive online TPD programs can successfully address the challenges of teaching STEM in virtual environments.
- The findings extend the existing research on TPACK by highlighting the importance of familiarization with diverse software tools in TPD. The DECODE model's focus on hands-on technology use and instructional design development offers new insights into how teachers can refine their technological integration strategies, particularly in STEM fields, where subject-specific technology demands are high.
- This study adds to the conversation about sustaining high-quality STEM education in a digital world by showing that STEM-TPD programs using the DECODE model not only empower teachers to adapt to virtual teaching environments but also foster a willingness to engage in future online TPD sessions. This demonstrates the potential for long-term benefits and engagement in STEM education through innovative online TPD models.

Indonesia and other countries (Philipsen et al., 2019). Online TPD offers a range of advantages, including time efficiency, conservation of energy and cognitive resources, as well as cost-effectiveness. Therefore, STEM-TPD programs through the online workshop activities are potentially positive in improving education quality and the common training model used is DECODE.

DECODE model is an acronym for *DEmonstrating* (DE), *COllaborating* (CO), and *DEbriefing* (DE). In this context, STEM teachers familiarize themselves with various technologies and software platforms to increase knowledge and skill in appraisal design, instructional design, and practical implementation. The model also supports teachers in applying STEM activities (Cheng et al., 2022) to increase skills in competency development. The specific competencies to be developed are TPACK abilities. Even though research on both STEAM and TPACK is growing rapidly (Karampelas, 2023). Nevertheless, research on how the DECODE model might improve STEM teachers' TPACK abilities, particularly in its online practices, is still scarce.

TPACK is the skills of STEM teachers in collaboration among learning topics, teaching methods, media, and technology selection. TPACK is essential for teachers as it helps them effectively understand and utilize technology to teach the content (Thohir et al., 2023). These skills consist of specific professional knowledge, namely technological knowledge (TK), content knowledge (CK), pedagogical knowledge (PK), pedagogical content knowledge (PCK), TPACK, and the interaction between two or more knowledge (Chai, 2016; Irwanto et al., 2022). The TPACK abilities develop individuals into professionals because the DECODE model can simultaneously support the implementation and access of technology, pedagogy, and learning materials (Wahono et al., 2022). Therefore, this study aims to provide answers to the following study questions, as follows:

1. How can the DECODE model measure the uniqueness and participants' responses to the online STEM-TPD?
2. How is the significance of TPD through the DECODE model on the teacher's TPACK enhancement?

THEORETICAL REVIEW

STEM Teacher Professional Development

STEM teachers are agents of change that can advance and shape the high quality of generations. Therefore, STEM-TPD is required to make it happen (Wahono et al., 2021). According to Awad et al. (2019), professional STEM teachers can be seen from their capabilities in language literacy, mathematics, and science. In addition, the four core competencies for teachers are pedagogical, professional, social, and personality competence.

The most effective and practical method for potential TPD is to increase information technology and communication (ICT) abilities. These abilities become the basis for developing 21st century learning innovation (Law et al., 2015). As a result, teachers should adapt to technological changes and self-trust in learning development (Balaban et al., 2023). In this context, the training to increase ICT skills is a priority in maintaining the quality of STEM teachers.

STEM education appears to improve students' global-level competitiveness in facing the 4.0 industrial revolution and the 21st century competition, particularly in science and technological innovation. This competitiveness is an individual's ability to reason and think critically, logically, and systematically (Martín-Páez et al., 2019). STEM learning must be applied with CK covering scientific methods, evidence-based reasoning, design principles, technical limitations, mathematical theories and constructions, pedagogy, and application technology (Utomo et al., 2018).

Furthermore, STEM learning focuses on real-life problem-solving, which includes many scientific disciplines and skills, such as the four integrated aspects. According to Wahono et al. (2020), STEM education can train students in interdisciplinary learning, particularly in concepts and theories related to daily life, through applying science, knowledge, and mathematics. This acts as a solution to experiencing the 21st century challenges and prepares learning participants when facing the world of employment and the new competition era. STEM-TPD via training or workshops is crucial in preparing all of them.

Professional development plays a significant role in enhancing TPACK abilities. Skillful STEM teachers integrating technology, PK, and understanding of subject content can create more meaningful and relevant learning experiences (Morales et al., 2022). Technology-based learning that supports the understanding of STEM concepts promotes problem-solving and increases students' critical and collaborative skills can be presented after mastering the TPACK (Thyssen et al., 2023). Moreover, engaging in continuous professional development is crucial for staying in line with the latest advancements in technology and learning methods. This practice is essential for effectively addressing the challenges in future educational contexts (Han et al., 2015). Finally, investment in STEM teacher development is a strategic step to increase the quality of education and prepare more competent generations in the digital era.

The online and offline professional development programs aim to improve the quality of national and international standards in the context of education. This idea is realizable through developing pedagogical, personality, social, and professional competencies (Christa et al., 2023). STEM-TPD programs are significant because very few have been conducted (Wahono et al., 2022). However, a challenge during and after the pandemic conditions is limiting the total number of participants in a group (Dhawan, 2020; Tagliente, 2023). The current exposure to online and distance learning has become daily "intakes" in all lines of life and teachers' worlds. Therefore, implementing online TPD programs is inevitable and has a similar positive potential for conducting offline TPD.

DECODE Model

DECODE model is an acronym for "DEmo-CO-design/teach-feedback-DEbriefing." Furthermore, it is a workshop model for STEM-TPD to increase TPACK abilities and provides customization to various educational technology and software platforms (Cheng et al., 2022). Moreover, the DECODE model can supply a picture of knowledge and abilities in instructional design, appraisal design, and practical implementation to apply STEM learning (Wahono et al., 2022). The model has three phases:

(1) DE–Teacher's demonstration.

(2) CO–Participants co-train by using ICT.

(3) DE–Participants co-teach feedback from one another and debrief lessons from previously mentioned phases.

In this context, the model is applied in one or two rounds. For example, DE-CO-DE-CO-DE can increase and strengthen teachers' mastery and a customization to STEM education technologies. However, the application of the model relates to the types of technologies applied. This issue may result in the collaboration of the TPACK abilities with technology access, pedagogy, and learning subjects (Cheng et al., 2022).

The latest challenges in the pandemic and post-pandemic era require appropriate steps to ensure that education rights are achievable through a platform supporting access to learning resources. DECODE model facilitates efforts to determine teachers' critical abilities regarding the affordability of innovative technologies in teaching practices, especially in subject matter selection, motivational empowerment, information presentation, activity design, and transitions in teaching (Cheng et al., 2022; Wahono et al., 2022). Finally, DECODE can facilitate teachers' TPACK capabilities towards a connected model for accessing technology, pedagogy, and subject matter. Based on the framework, the model in this current study is implemented for training to increase and maintain the competence or professionalism of STEM teachers in biology learning. This professionalism is achieved by strengthening information and communication technology in a web-based platform. The fundamental consideration of the application is an accessibility orientation in a broader way (Poortman et al., 2021) to reach the target users without any limits. The web platform for developing and implementing STEM-based science learning training with the DECODE model will become a tested training package to support the expansion of the positive impact of the implementation.

Technological Pedagogical and Content Knowledge

The abilities of TPACK are the collaboration among knowledge, skill, and competence of teachers in technological implementation in learning activities. These describe how teachers design, apply curriculum, and conduct teaching activities while guiding students to think, learn, and practice digital technology (Irwanto et al., 2022). According to Mumcu et al. (2022), self-confidence levels in teaching activities by applying technology and engineering are lower than in integrating the learning of mathematics and science. The knowledge of technology only relates to several ways of using certain technologies. This is due to a lack of literacy and understanding of using technology in learning activities (Chai, 2016). Therefore, the abilities are required to change thinking patterns and self-confidence

Table 1. Distribution of study participants

Variables	Categories	Total	Percentage (%)
Sex	Man	27	29.67
	Woman	64	70.33
Education	Bachelor	77	84.61
	Magister	14	15.39
Years of teaching	< 10 years	68	74.72
	> 10 years	23	25.28
Area of specialization	Science	73	80.21
	Technology	4	4.39
	Mathematics	9	9.90
	Others	5	5.50
School location	Urban	62	68.13
	Sub-urban	21	23.08
	Rural	8	8.79

levels as well as keep pace with technological development in the education sector (Zhu & Liu, 2020).

There are three major components of TPACK, including TK, PK, and CK. The components are relates to one another, producing seven subtypes, namely TK, PK, CK, TCK, PCK, TPK, and TPACK. The possession of the entire components can generate an effective, efficient, and attractive learning process (Cengiz, 2015). A way of increasing teachers' TPACK abilities is through the introduction and training of using learning platforms.

Following the current development, many learning platforms are ready with different advantages and features. Therefore, the platforms are directly proportional to the completeness of the features. A learning platform with perfect features is *cloud class room* (CCR) developed with an interactive response system (Wahono et al., 2021). Moreover, the advantages of CCR are that teachers become more active in using technology and providing practical STEM content and learning with technological applications (Cheng et al., 2022). The features include formative assessments, real-time feedback, multimedia presentations, instant group formation, role exchange between teachers and students, follow-up tools, and timely feedback support (Cheng et al., 2022). Therefore, the study team uses CCR platform with the TPD as a TPACK training learning platform for STEM teachers.

MATERIALS AND METHODS

Participants

This study included a total of ninety-one secondary school teachers who come from many regions such as Central and East Java provinces. These two provinces are the first and second largest population province in Indonesia. The origin of schools from the participants varies from urban, suburban, and rural areas. Before conducting the study, the related information regarding participation in TPD was complete. The distribution of study participants in detail are shown in **Table 1**.

The data on the distribution of the respondents cover sex, education, years of teaching, area of specialization, and school location. The distribution data show the diversity of the participants in organizing STEM-TPD with the online DECODE model. The confidentiality of the identity of teachers who participated was guaranteed since the objectives were explained in detail.

There are three instructors involved in this research. Besides being a lecturer, each instructor is an expert in STEM, TPACK, and online-based teaching. Moreover, all instructors have doctorate degrees and teaching experience of more than ten years. Before conducting TPD, the three instructors met to match the perception of the implementation and consistency of the relationship with each material content. All the instructors are on the research team for the project.

Study Procedures and Design

This study aims to determine the occurrence, (uniqueness, response and effectivity on TPACK), of online STEM-TPD with DECODE model. Finally, this study aim's is to know how the effectiveness of the TPD through DECODE model on the teacher's TPACK. To address these research questions, we designed this study as a pre-experimental design pre-test-post-test, a type of quasi-experimental design.

The TPD model used is online DECODE consisting of three stages. The stages include

(1) DE: Teacher's DEmonstration (trainer demonstrations),

(2) CO: Students CO-train with the use of CCR, participants CO-design a classroom integrated closely with educational technology, and

(3) DE: Participants receive feedback from each other and DEbrief what is learned through the stages mentioned above (Cheng et al., 2022).

The details of phases and description of online DECODE model used in this study are shown in **Table 2**.

Table 2. Phases and description of online DECODE model (Cheng et al., 2022)

No	Phases	Objectives	Training models
1	*Teacher's demonstrations*	Sharpens the understanding of STEM education	Instructors supply STEM education training materials through presentation and discussion.
		Increases the understanding of teacher TPACK skills	Instructors supply TPACK training materials through presentation and discussion
		Improves the ICT skills (*ICT*)	Instructors demonstrate the ICT function through the CCR.
2	*Students co-train the use of ICT*	Increases the TCK skills (*TCK*) to the participants with ICT (*ICT*)	The participants form a group with 4-6 members, each in turn acts as a teacher and the teaching participants to train the ICT operation through the CCR.
3	*Students co-design an ICT-an integrated course*	Increases the TPACK participants (*TPACK*) in a disciplined manner	Each group is encouraged to develop skills to use the CCR platform. Each group requires the accomplishment of concept maps, teaching content and questions on the CCR platform.
4	*Students co-teach the course and receive feedback*	Increase teachers' TPACK abilities	Each group, one by one, demonstrates each skills to other educated participants with direction and ICT. After doing the demonstration, other participants gave feedback to this group.

Online DECODE was carried out through virtual and combined mode with a hardcopy to form a mixed-mode training model. The delivery of material packages and manuals to the participants aims to maximize the achievement and interaction of long-distance teaching. The participants had received the materials and packages at least three days before TPD was carried out. In particular, the validated package development comprises an innovative website homepage (https://stem.fkip.unej.ac.id), STEM workshop module package, and an assessment. The packages are the results of the project accomplished one year ago (Wahono et al., 2022). Therefore, total training hours comprising self-learning activities through manual books and online workshops amount to 72 hours, comprising of 10 and 62 hours for online and self-learning activities.

We performed pre-/post-questioner instrument to collect the quantitative data. The questionnaire comprises some domains: TK, PK, PCK, TCK, and TPACK. The instrument was well-developed and validated in the previous study about the assessment package of the online STEM-TPD packages with the DECODE model (Wahono et al., 2022). In addition, We utilized a polling survey via Zoom platform to ask about the participant's perception of the TPD training in general and their viewpoints on TPACK abilities after accomplishing the activities. The polling was content validated with a score of 87.5% by the research team before the study.

Data Analysis Methods

To answer the formulation of the first problem (how the online STEM-TPD through the DECODE model in/post-pandemic COVID-19 occurs and the possibility uniqueness), an analysis-based activity was conducted. Moreover, through an open questionnaire after implementing online TPD, the participants' opinions were asked concerning the implementation and viewpoint on the progress of TPACK abilities. We presented the data from their responses by a descriptive analysis. As a refinement of this study and project, the effectiveness of TPD was analyzed through DECODE model on the Teacher's TPACK. The effectiveness directs to the TPACK knowledge and skills of STEM teachers before and after accomplishing the workshop. To carry out the task, the paired-sample t-test analysis was used through the software of Jeffreys's amazing statistics program version 0.14.1. Moreover, to strengthen the analysis results, the effect size with Cohen's d became crucial in the statistical analysis. The assumption test of homogeneity and data normality was also carried out before the parametric statistic test with paired-sample t-test.

RESULTS

The study discussed the implementation of TPD for STEM teachers by online model. TPD was a well-planned and prepared activity to increase TPACK abilities of teachers. In general, the implementation and progress of TPD as well as the effectiveness were uncovered.

TPD Through Online DECODE Model

The first answerable objective is related to organizing STEM-TPD with the online DECODE model. The participants comprised 91 teachers with various STEM disciplines in East Java and Central Java provinces, Indonesia. In conducting the online TPD implementation, the CCR platform was applied as a major media in the curriculum development and learning simulation progress. Furthermore, Zoom application media was used as the introductory media when interacting in online TPD process.

In this study, TPD used the online DECODE model to increase STEM teachers' TPACK knowledge and skills. The one-day TPD training went on for nine hours from the participant registration to the closing of the training. The DECODE model comprised of DEmonstrating, COllaborating and DEbriefing phase, and the training was carried out as scheduled. The demonstrating phase

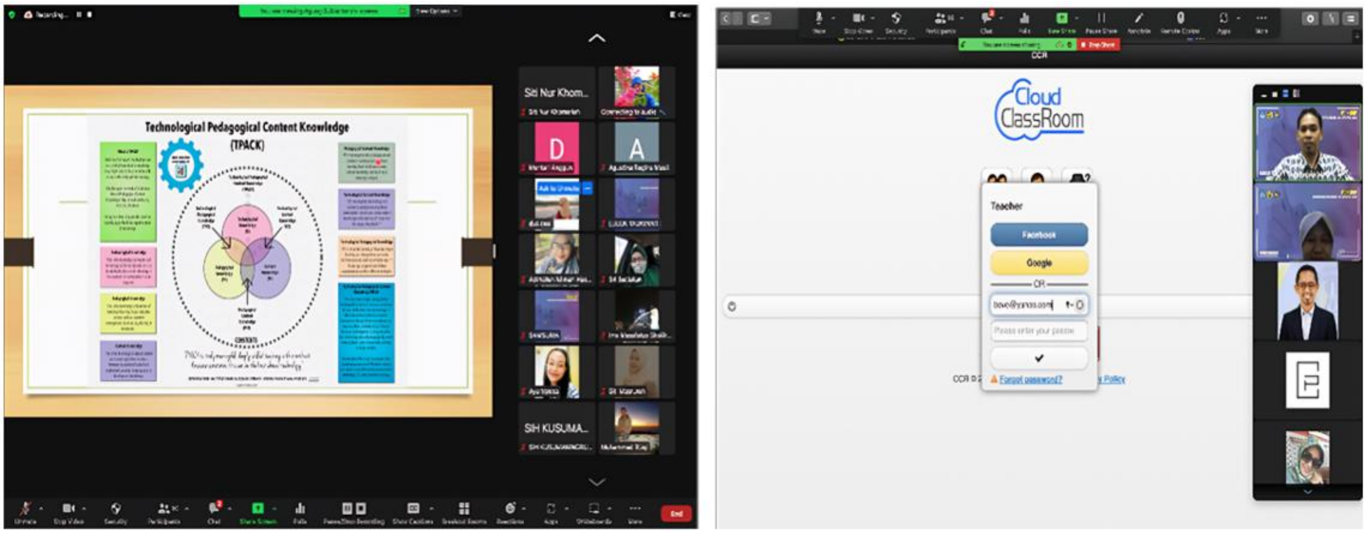

Figure 1. The demonstrating phases of the online DECODE model: (a) TPACK exploration & (b) CCR demonstration (Source: Authors' own elaboration)

contained preliminary knowledge to build the consciousness of TPACK teachers, as shown in part a in **Figure 1**. The instructor shows the concepts of what, why, and how TPACK functions and the important role in facilitating learning activities. The activity becomes a strong foundation for teachers for the next phase in DECODE model. After the phase, another instructor came and discussed knowledge about the characterization of STEM teachers and education. The demonstrating phase ends with a practical illustration using online platforms in the learning process, as shown in part b in **Figure 1**.

In CO phase, all participants actively co-train the use of ICT and divided into small groups using the breakout room feature on the Zoom application. In this phase, learning was carried out together using CCR as the design. Knowledge and skill that they learned from instructors' demonstration in the previous phase was also shared from one another by directly practicing each device. Learning design is started after all members of the groups comprehend the technicalities of using CCR. The selected learning topics depend on the approval of the group members. An example of the selected topics relates to "climate change" and for around two hours (2 × 60 minutes), a curriculum is developed to be presented in the main room on Zoom application. The presentation phase (co-teach) is also part of the CO phase for DECODE model. In the co-teaching activities, the participants actively used and explored various features of CCR when acting as teachers or students.

The debriefing is the final phase conducted by the TPD participants. During this phase, each participant provided feedback to one another regarding the respective previous activities. In addition, expert instructors also presented evaluation and feedback on CO implementation conducted. For example, feedback and comments of the participants are, as follows:

> "From what we have done previously, I feel that I have to master the material characteristics at first. Therefore, I can design it to be a meaningful learning by using CCR."

The feedback and comments of the participants supported the responses from the instructors. The support is like,

> "It closely relates to what we teach, the method used, particularly on online media, and what and how to use technology to achieve the learning objectives. The skills and understanding of the ICT are crucial in online learning besides learning materials and methods."

In the debriefing phase, many participants state challenges and obstacles faced in the co-designing and co-teaching phases conducted previously.

After organizing the online TPD, the participants' opinions are asked about the training in general and the viewpoints on TPACK abilities after accomplishing the activities. These observations contribute quantitatively to the assessment of the training's effectiveness and the feasibility of replication. The results also inform the possibility of conducting similar sessions in the future within Indonesia and other countries. **Table 3** shows a portrait of the participant's perception of the TPD training. According to STEM teachers, TPD is essential and can increase TPACK knowledge and abilities. In addition, most participants also prefer to be included in similar training in the future. Some participants asked for direct assistance in implementing the skills needed to apply in respective schools. Therefore, TPD objectives with online DECODE model are reachable and appropriate to the expectations.

Table 3. Participants responses to the online TPD DECODE online

Questions	Agreed response percentage (%)							
	Male (N = 27)				Female (N = 64)			
	S (N = 20)	T (N = 2)	M (N = 3)	O (N = 2)	S (N = 53)	T (N = 2)	M (N = 6)	O (N = 3)
Do you feel this training is beneficial to increase a teacher's TPACK knowledge and skill?	95	100	100	100	98.11	100	100	100
Are you willing to participate in the training if we will hold it again shortly?	90	100	66.70	100	94.34	100	83.33	100

Note. S: Science teacher; T: Technology teacher; M: Math teacher; & O: Other teachers

Table 4. Effectiveness of DECODE model on the teacher's TPACK

Components	N*	Pre-test (SD)	Post-test (SD)	t	*p*	*d*
Technological knowledge (TK)	68	70.56 (12.24)	85.45 (8.84)	4.45	< .001	.92
Pedagogical knowledge (PK)	68	75.77 (10.38)	83.33 (6.57)	2.23	.047	.68
Content knowledge (CK)	68	81.23 (8.98)	85.34 (4.96)	1.77	.234	.32
PCK knowledge (PCK)	68	72.05 (11.87)	83.78 (6.45)	2.86	.024	.77
TCK knowledge (TCK)	68	68.34 (12.46)	82.57 (7.90)	4.33	< .001	.87
Technological pedagogical and content knowledge (TPACK)	68	66.78 (9.76)	79.23 (8.24)	4.21	< .001	.82

Note. *The total number of participants was 91, but only 68 completed the questionnaire

Effectivity of the TPD With DECODE Model on the Teacher's TPACK

After observing the TPD process and listening to the participants' opinions, the formulation of the second study problem is related to the effectiveness of the training activity. Effectivity reflects the level of success and usefulness and allow other parties to conduct a similar activity in the future. This refers to the TPACK knowledge and skills of STEM teachers before and after completing the workshop. The analysis results on the effectiveness of the activities can be shown in **Table 4**, as follows.

The results of statistical analysis show that TPD with the online DECODE model effectively improves TPACK knowledge and skills of STEM teachers ($t = 4.21$; $p \leq .001$; $d = .82$). In specific, TK, PK, PCK, TCK, and TPACK domains show a significant improvement between pretest and post-test value. For CK domain, there is no significant difference between pretest and post-test scores ($t = 1.77$; $p = .234$; $d = .32$). However, these results show that online STEM-TPD teachers have increased the understanding and ability of TPACK after participating in online STEM-TPD workshop.

DISCUSSION

Some narratives taken and discussed from the results include online STEM-TPD through DECODE model as an alternative to maintaining teacher quality during and after pandemic. Another narrative to review is the understanding and ability of TPACK enhanced by online TPD through DECODE Model. The feasibility of discussing the two narratives will be comprehensively explained based on the study results we have uncovered.

Online STEM-TPD Through DECODE Model as an Alternative to Maintenance Teacher Quality in the Internet Era

Online TPD through DECODE model can become an alternative method to maintaining and improving teacher quality, especially in/post-pandemic COVID-19 conditions as well as in the digital era. The model is a systematic framework applied to enhance teacher development and positively impact student learning outcomes (Cheng et al., 2022). This can be used as an alternative to traditional methods (Niemi, 2015) of maintaining teacher quality (Wahono et al., 2022). The current study has shown that TPD gives some advantages, namely online communities, data-driven feedback, ongoing assessment, and cost-effectiveness.

Take an example, let's say the online communities. Online or virtual communities and social networks can enhance collaboration and peer learning among teachers. In the result part, the teachers collaboration process was discussed through co-teach, co-train, and co-design. These online forums and discussion groups allow teachers to share experiences, best practices, and resources, creating a supportive professional network (Martono & Salam, 2017). Moreover, the collaborative aspect of online learning can sustain teacher motivation and growth.

Online professional development can be more cost-effective than traditional face-to-face methods. This reduces expenses for travel, venue rental, and printed materials, allowing educational institutions to allocate resources more efficiently (Philipsen et al., 2019). As evidence, the number of participants in the online STEM-TPD through DECODE model is 91. They came from many places and schools around the two biggest provinces in Indonesia. This situation shows how powerful and how much the TPD is in/post-pandemic COVID-19 conditions, especially for STEM teachers.

In the online DECODE model, the participants of STEM teachers are accustomed to various technology and software platforms (e.g., CCR). The knowledge and abilities of assessment design, instructional design, and practical implementation are improved. By leveraging technology and personalized learning pathways, educational institutions can ensure that the teachers receive ongoing support and development, benefiting teachers and students (Chaka et al., 2022). DECODE model also helps STEM teachers with the application during learning situations. With this condition, STEM teachers can increase their abilities in developing specific competencies, namely TPACK abilities.

STEM Teacher's Understanding and Ability of TPACK Enhanced by the Online TPD Through DECODE Model

The results show that TPD with online DECODE model effectively increases STEM teachers' TPACK knowledge and skills. All the TPD phases with online DECODE model play a substantial role in the improvement (Cheng et al., 2022). The demonstrating phase gives excellent examples and knowledge for development demand of TPACK teachers' knowledge and skills. In this phase, there is material delivery about what and how the TPACK is in the capacity of the teacher. Furthermore, online teachings are directly taught to manage proper and effective learning. For example, in the CO phase, the participants co-teach, co-train, and co-give feedback to improve TPACK automatically. Participants with limited skills and knowledge of technology have the opportunity to enhance proficiency through learning from peers possessing advanced technological skills and knowledge (Boylan et al., 2023). We can state that peer teaching and scaffolding occur in reality. The proficiency of participants in matching materials and methods with specific characteristics has improved due to the transfer of knowledge from experienced teachers. It is provable from some statements described in the research results section.

Furthermore, this study shows that improvement in the participants' CK domain is not significant. Our strong prediction because it happened is due to the participants' sufficient CK. In the TPD, CK is not the main focus. The primary focus is on the participants' comprehension and skills in using appropriate technological platforms for online learning. Increasing the understanding of CK needs a lot of time and reading (Großsched et al.. 2018), and the TPD cannot accommodate the concept. Therefore, TPD with online DECODE model is very promising for increasing TPACK teachers.

Indeed, the implementation of the online DECODE model in Teacher TPD programs presents a highly effective method for enhancing STEM teachers' TPACK capabilities. Each phase of the DECODE model contributes uniquely to the growth of both technological skills and pedagogical strategies, particularly through collaborative engagement among teachers (Cheng et al., 2022; Wahono et al., 2022). In the co-teaching phase, for example, peer-to-peer interactions foster not only the sharing of knowledge but also create a dynamic learning environment where teachers with varying levels of expertise collaborate to elevate their competencies. This shared learning process is especially beneficial for teachers with limited technological proficiency, as they are scaffolded by their more experienced peers, leading to a collective uplift in their abilities to integrate technology in a pedagogically sound manner (Cengiz, 2015; Niemi, 2015). The research further underscores that while CK improvement is not a significant outcome of this TPD model, the focus on technological and pedagogical integration aligns well with the evolving demands of online education, making the DECODE model a valuable approach for enhancing TPACK within STEM education. This structured, phase-driven framework provides STEM educators with practical, hands-on experiences that directly influence their classroom practices, bridging gaps between theory and application.

CONCLUSION

This study concludes that integrating the STEM-TPD framework with the online DECODE model plays a vital role in sustaining high teaching quality in the evolving landscape of the internet era. By addressing the challenges of remote or digital teaching environments, the DECODE model demonstrates its effectiveness as an adaptable and practical alternative for ensuring the consistent professional growth of educators. Specifically, this approach not only preserves teaching standards during challenging circumstances, such as those posed by global disruptions or shifts to online learning, but also significantly enhances teachers' understanding and application of the TPACK framework. The findings underscore that the model promotes a balanced integration of technology, pedagogy, and subject matter knowledge, empowering teachers to deliver more effective and engaging STEM education.

Consequently, this study strongly recommends that educational policymakers, school administrators, and training providers adopt the STEM-TPD framework with the DECODE model in various professional development contexts. Whether applied in formal teacher training programs, professional development workshops, or other capacity-building initiatives, this model can be instrumental in equipping educators with the skills necessary to thrive in both traditional and digital teaching environments.

Concerning the limitations, not all participants attended the TPC activities until the end of the training. The condition led to an analysis of only 74.762% of the total collected data, out of 91 participants. Approximately 74.72% of the participants actively attended until the end of the training and the number was substantial for online training. Another limitation was that the proportion of STEM teachers' discipline was imbalanced. In this study, science teachers were dominant, and others had a smaller proportion. However, an overview of online TPD model was stated and was beneficial for better teacher quality.

Future analyses can be carried out to explore the difficulties and challenges of teachers during the training process. Information on the obstacles and challenges of participants is essential for many parties and exploring the effect of training in schools where participants come from is an ambitious project. These studies can focus on the teachers' quality in teaching (TPACK) or the effectiveness of the learning results achieved. Therefore, the results have become the core reference in developing teacher professionalism in the online learning period and advances in information and communication technology.

Author contributions: BW: finalising the manuscripts; **SH:** analising data and constructing research findings; **AWS:** analising data and constructing research findings; **JAMB:** elaborating research findings and discussion; **MSM:** elaborating research findings and discussion. All authors agreed with the results and conclusions.

Funding: This study was supported by the National Competitive Basic Grant Research, grant scheme from Indonesian Ministry of Education Culture Research and Technology 2023 (023/ES/PG.02.00.PL/2023).

Acknowledgments: The authors would like to thank the National Competitive Basic Grant Research, the Grant Scheme of the Indonesian Ministry of Education Culture Research and Technology 2023 for funding the study. The authors would also like to thank the Institute for Research and Public Services, University of Jember for all the facilities and support that have been given until the final results.

Ethical statement: The authors stated that the ethical requirement of this research was approved by ethical committee of the first author institution (University of Jember) on April 14, 2023 (Approval code: 3533/UN25.3.1/LT/2023). Written informed consents were obtained from the participants.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Awad, N. A., Salman, E., & Barak, M. (2019). Integrating teachers to teach an interdisciplinary STEM-focused program about sound, waves and communication systems. *European Journal of STEM Education, 4*(1), Article 5. https://doi.org/10.20897/ejsteme/5756

Balaban, I., & Rienties, B., & Winne, P. (2023). Information communication technology (ICT) and education. *Applied Sciences, 13*. Article 12318. https://doi.org/10.3390/app132212318

Boylan, M., Adams, G., Perry, E., & Booth, J. (2023). Re-imagining transformative professional learning for critical teacher professionalism: A conceptual review. *Professional Development in Education, 49*(4), 651-669. https://doi.org/10.1080/19415257.2022.2162566

Cengiz, C. (2015). The development of TPACK, technology integrated self-efficacy and instructional technology outcome expectations of preservice physical education teachers. *Asia-Pacific Journal of Teacher Education, 43*(5), 411-422. https://doi.org/10.1080/1359866x.2014.932332

Chai, C. S., Koh, J. H. L., & Tsai, C. C. (2016). A review of the quantitative measures of technological pedagogical content knowledge (TPACK). In M. C. Herring, M. J. Koehler, & P. Mishra (Eds.), *Handbook of technological pedagogical content knowledge (TPACK) for educators* (pp. 87-106). Routledge. https://doi.org/10.4236/jss.2022.1010006

Chaka, C., Nkhobo, T., & Lephalala, M. 2022. Leveraging student engagement through MS Teams at an open and distance e-learning institution. *Journal of Education and e-Learning Research, 9*(3), 136-146. https://doi.org/10.20448/jeelr.v9i3.4102

Cheng, P-H., Molina, J., Lin., M-C., Liu., H-H., Chang, C-Y. (2022). A new TPACK training model for tackling the ongoing challenges of COVID-19. *Applied System Innovation, 5*(32). https://doi.org/10.3390/asi5020032

Chiu, T. K., Chai, C. S., Williams, P. J., & Lin, T.-J. (2021). Teacher professional development on self-determination theory-based design thinking in STEM education. *Educational Technology and Society, 24*(4), 153-165. https://doi.org/10.30191/ETS.202110_24(4).0012

Christa, S., Asterhan, C., & Lefstein, A. (2023). The search for evidence-based features of effective teacher professional development: A critical analysis of the literature. *Professional Development in Education, 50*(1), 11-23. https://doi.org/10.1080/19415257.2023.2283437

Culduz, M. (2024). Benefits and challenges of e-learning, online education, and distance learning. In L. Gray, & S. Dunn (Eds.), *Incorporating the human element in online teaching and learning* (pp. 1-27). IGI Global. https://doi.org/10.4018/979-8-3693-4131-5.ch001

Dhawan, S. (2020). Online learning: A panacea in the time of COVID-19 crisis. *Journal of Educational Technology Systems, 49*(1), 5-22. https://doi.org/10.1177/0047239520934018

Even-Zahav, A., Widder, M., & Hazzan, O. (2022). From teacher professional development to teacher personal-professional growth: The case of expert STEM teachers. *Teacher Development, 26*(3), 299-316. https://doi.org/10.1080/13664530.2022.2052947

Großschedl, J., Mahler, D., & Harms, U. (2018). Construction and evaluation of an instrument to measure content knowledge in biology: The CK-IBI. *Education Sciences, 8*. Article 145. https://doi.org/10.3390/educsci8030145

Han, S., Yalvac, B., Capraro, M. M., & Capraro, R. M. (2015). In-service teachers' implementation and understanding of STEM project based learning. *Eurasia Journal of Mathematics, Science and Technology Education, 11*(1), 63-76. https://doi.org/10.12973/eurasia.2015.1306a

Irwanto, I., Redhana, W., & Wahono, B. (2022). Examining perceptions of technological pedagogical content knowledge (TPACK): A perspective from Indonesian pre-service teachers. *Jurnal Pendidikan IPA Indonesia, 11*(1), 142-154. https://doi.org/10.15294/jpii.v11i1.32366

Karampelas, K. (2023). Examining the relationship between TPACK and STEAM through a bibliometric study. *European Journal of Science and Mathematics Education, 11*(3), 488-498. https://doi.org/10.30935/scimath/12981

Law, N., Kampylis, P., & Punie, Y. (2015). *Pathways to enhance multilevel learning for scaling up systemic ICT-enabled learning innovations: Lessons from 7 European and Asian cases*. Springer. https://doi.org/10.1007/978-981-287-537-2_10

Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education, 103*(4), 799-822. https://doi.org/10.1002/sce.21522

Martono, F., & Salam, U. (2017). Students' learning in asynchronous discussion forums: A meta-analysis. *International Journal of Information and Communication Technology Education, 13*(1), 48-60. https://doi.org/10.4018/IJICTE.2017010105

Morales, E., Avilla, R., Sarmiento, C., Anito Jr, J., & Elipane, L. (2022). Experiences and practices of STEM teachers through the lens of TPACK. *Journal of Turkish Science Education, 19*(1), 237-256. https://doi.org/10.36681/tused.2022.120

Mumcu, F., Uslu, N. A., & Yıldız, B. (2022). Investigating teachers' expectations from a professional development program for integrated STEM education. *Journal of Pedagogical Research, 6*(2), 44-60. https://doi.org/10.33902/JPR.202213543

Niemi, H. (2015). Teacher professional development in Finland: Towards a more holistic approach. *Psychology, Society and Education, 7*(3), 279-294. https://doi.org/10.25115/psye.v7i3.519

Perry, E., & Booth, J. (2021). The practices of professional development facilitators. *Professional Development in Education, 50*(1), 144-156. https://doi.org/10.1080/19415257.2021.1973073

Philipsen, B., Tondeur, J., Roblin, N. P., Vanslambrouck, S., & Zhu, C. (2019). Improving teacher professional development for online and blended learning: A systematic meta-aggregative review. *Educational Technology Research and Development, 67*(5), 1145-1174. https://doi.org/10.1007/s11423-019-09645-8

Poortman, C. L., Brown, C., & Schildkamp, K. (2021). Professional learning networks: A conceptual model and research opportunities. *Educational Research, 64*(1), 95-112. https://doi.org/10.1080/00131881.2021.1985398

Tagliente, L., Bigliardi, B., Dolci, V., Pini, B., Notaro, A., Petroni, A., & Gianatti, E. (2023). Pandemic and education: A bibliometric analysis of ICT use in research literature. In *Proceedings of the 16th annual International Conference of Education, Research and Innovation* (pp. 6775-6783). IATED. https://doi.org/10.21125/iceri.2023.1693

Thohir, M. A., Ahdhianto, E., Mas'ula, S., April Yanti, F., & Sukarelawan, M. I. (2023). The effects of TPACK and facility condition on preservice teachers' acceptance of virtual reality in science education course. *Contemporary Educational Technology, 15*(2), Article ep407. https://doi.org/10.30935/cedtech/12918

Thyssen, C., Huwer, J., Irion, T., & Schaal, S. (2023). From TPACK to DPACK: The "digitality-related pedagogical and content knowledge"-model in STEM-education. *Education Sciences, 13*, Article 769. https://doi.org/10.3390/educsci13080769

Utomo, A.P., Narulita, E., Yuana, K., Fikri, K., Wahono, B. (2018). Students' errors in solving science reasoning-domain of trends in international mathematics and science study (TIMSS). *Jurnal Pendidikan IPA Indonesia, 7*(1), 48-53. https://doi.org/10.15294/jpii.v7i1.11352

Wahono, B., Chang, C. Y., & Khuyen, N. T. T. (2021). Teaching socio-scientific issues through integrated STEM education: An effective practical averment from Indonesian science lesson. *International Journal of Science Education, 43*(16), 2663-2683. https://doi.org/10.1080/09500693.2021.1983226

Wahono, B., Hariyadi, S., & Subiantoro, A. W. (2022). The development of an online STEM teacher professional development package with the DECODE model: An innovative teacher's quality maintenance. *Eurasia Journal of Mathematics, Science and Technology Education, 18*(12), Article em2191. https://doi.org/10.29333/ejmste/12647

Wahono, B., Lin, P.-L., & Chang, C.-Y. (2020). Evidence of STEM enactment effectiveness in Asian student learning outcomes. *International Journal of STEM*

Education, 7, Article 36. https://doi.org/10.1186/s40594-020-00236-1

Zhu, X., & Liu, J. (2020). Education in and after COVID-19: Immediate responses and long- term visions. *Postdigital Science and Education, 2*(3), 695-699. https://doi.org/10.1007/s42438-020-00126-3

https://www.ejmste.com