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Improving the TPACK Competence of Prospective Physics Teachers Through the Use of the Nearpod Application

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Abstract

Purpose of Study: This study aims to examine the effectiveness of Nearpod-based training in improving the Technological Pedagogical Content Knowledge (TPACK) competence of prospective physics teachers in designing physics learning tools.

Methodology: This study employed a quantitative approach with two analytical components. The first component used a One-Group Pretest–Posttest design involving 19 prospective physics teachers who participated in Nearpod-based training and teaching simulations. The second component involved a final TPACK questionnaire administered to 60 prospective physics teachers from four universities. Data were analyzed using N-Gain, the Wilcoxon Signed-Rank Test, and the Rasch Model with Winsteps software.

Main Findings: The results showed that the mean TPACK score increased from 76.05 in the pre-test to 91.50 in the post-test, with an N-Gain value of 0.65, indicating moderate improvement. The Wilcoxon test produced a significance value of 0.000, confirming a statistically significant difference between pre-test and post-test scores. Rasch analysis showed that 85% of respondents were in the moderate TPACK category. The Wright Map further indicated that Technological Knowledge, Content Knowledge, and some aspects of Pedagogical Knowledge were relatively easier to master, whereas Pedagogical Content Knowledge, Technological Pedagogical Knowledge, and holistic TPACK remained more challenging.

Novelty/Originality of This Study: This study highlights Nearpod not only as a digital learning platform, but also as a pedagogical design space that supports prospective physics teachers in integrating physics content, interactive digital features, formative assessment, student engagement, and feedback within technology-enhanced learning.

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INTRODUCTION

Technological advances in the digital age require educators to be able to integrate technology into learning, including in the field of physics. Technological Pedagogical Content Knowledge (TPACK) is an important framework for prospective teachers in developing effective teaching skills with technology. TPACK is knowledge about teachers' skills in using technology based on an analysis of material characteristics and pedagogical aspects in learning (Salleh et al., 2025). TPACK combines three main aspects: Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK), resulting in new combinations of knowledge such as Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK), and Technological Pedagogical Knowledge (TPK). The integration of TPACK into the teacher education curriculum is necessary to ensure the readiness of prospective teachers to face the challenges of modern learning. In physics education,

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this readiness is particularly important because many concepts are abstract, invisible, or mathematically represented, requiring prospective teachers to design learning that connects conceptual explanation, visualization, simulation, and student interaction.

Several previous studies have shown that prospective physics teachers' mastery of TPACK still needs to be improved, especially in terms of technology. The results of the study show that although prospective physics teachers' understanding of the material and pedagogy is good, the use of technology in learning is still limited. Another study also found that prospective physics teachers still need further training in the use of technology as a learning aid. The design of teacher education curricula must emphasize more authentic technology-based learning scenarios to improve TPACK integration in real classrooms (Tschönhens et al., 2024). Training for prospective teachers must place greater emphasis on the integration of technology in pedagogy, not just on technical skills alone (Tondeur et al., 2025).

One strategy to improve TPACK is through the use of digital applications in learning. Research results show that the use of Google Apps significantly improves the TPACK skills of physics teachers because it facilitates more flexible and interactive learning (Rukmana & Handayani, 2022). In addition, the implementation of Experimental Physics learning with an online-STEM approach has been proven to improve the TPACK abilities of prospective physics teachers from the 'Fair' to 'Very Good' category. The online-STEM approach is able to significantly improve the technological skills of prospective physics teachers. However, different digital applications support different parts of learning; some function mainly as content repositories, assessment tools, or communication platforms. Therefore, the selection of a technology platform should be aligned with the pedagogical and content-specific needs of physics learning.

However, other studies also reveal that in practice, the use of technology in physics learning is still basic, limited to visualization tools such as videos and animations, without comprehensive integration into learning. This confirms that more innovative and interactive strategies are needed in developing the TPACK of prospective physics teachers. Nearpod was selected in this study because it provides an integrated environment that combines interactive presentation, formative assessment, collaborative activities, multimedia visualization, and simulation-based learning within a single learning flow. These affordances are relevant to physics learning, which often involves abstract concepts such as force, energy, waves, electricity, and microscopic phenomena that require visualization and dynamic representation. Nearpod also allows prospective teachers to embed simulations, videos, quizzes, polls, and open-ended responses, enabling students to observe, predict, explain, interact, and receive feedback during learning. Compared with digital tools that focus only on presentation, quiz delivery, or communication, Nearpod supports the simultaneous integration of technology, pedagogy, and physics content, making it suitable for strengthening prospective physics teachers' TPACK. Several studies show that the use of interactive learning media through the Nearpod application can significantly increase students' interest, motivation, and learning outcomes (Abdullah et al., 2022; Diana et al., 2026).

A number of studies have shown the effectiveness of Nearpod in increasing student engagement, conceptual understanding, and teachers' digital skills (Al-Samarraie & Saeed, 2018; Hakami, 2020). Nevertheless, most previous studies have focused primarily on student engagement, motivation, learning outcomes, or general digital skills, while fewer studies have examined Nearpod as a structured training context for developing prospective physics teachers' TPACK. This gap is important because prospective physics teachers not only need to operate digital tools, but also need to transform physics content into technology-enhanced pedagogy that supports visualization, simulation integration, interaction, and formative feedback. Thus, this study aims to address this gap by examining the improvement of prospective physics teachers' TPACK competence through Nearpod-based training, with specific attention to how the platform supports the integration of physics content, pedagogical strategies, and digital technology. The research question in this study is: how does the use of the Nearpod application improve the TPACK competence of prospective physics teachers in physics learning?.

METHOD

This study employed a quantitative approach with two complementary analytical components. The first component used a pre-experimental One-Group Pretest-Posttest design (F. Su & Zou, 2026) to examine the effect of the Nearpod-based intervention on students' TPACK competence. The intervention was conducted at Samudra University in Langsa City, Aceh Province, involving 19 students from the Physics Education Program in the 2024-2025 academic year. The participants were students in their seventh semester or above who had completed microteaching courses. These same 19 students completed the pre-test, participated in four sessions of Nearpod-based training, developed physics learning tools, conducted teaching simulations that were observed by the researchers, and completed the post-test. Accordingly, the Wilcoxon signed-rank test was applied only to the paired pre-test and post-test data from the Samudra University intervention group (N = 19).

The second component involved administering a final TPACK questionnaire to a broader group of 60 students from physics education programs at Samudra University, Bengkulu University, Indonesia University of Education, and Malikussaleh University. This questionnaire was used to map students' TPACK competency profiles on a cross-sectional and evaluative basis after the training activities. The questionnaire dataset was not part of the paired pre-test-post-test intervention; instead, it was analysed using the Rasch Model. Thus, this study involved two analytical samples: 19 students for the Nearpod intervention and Wilcoxon analysis, and 60 students for the final TPACK questionnaire and Rasch Model analysis.

The research procedure consisted of four main stages: instrument preparation, data collection, data analysis, and conclusion drawing. Instrument preparation included developing, justifying, validating, and revising the TPACK instruments before implementation. Data collection included the pre-test, intervention, teaching simulation, observation, and post-test for the intervention group, as well as the final TPACK questionnaire for the broader respondent group. Data analysis involved the Wilcoxon signed-rank test for the intervention data and the Rasch Model with the assistance of the Winsteps application for the questionnaire data. The overall research flow is presented in Figure 1.

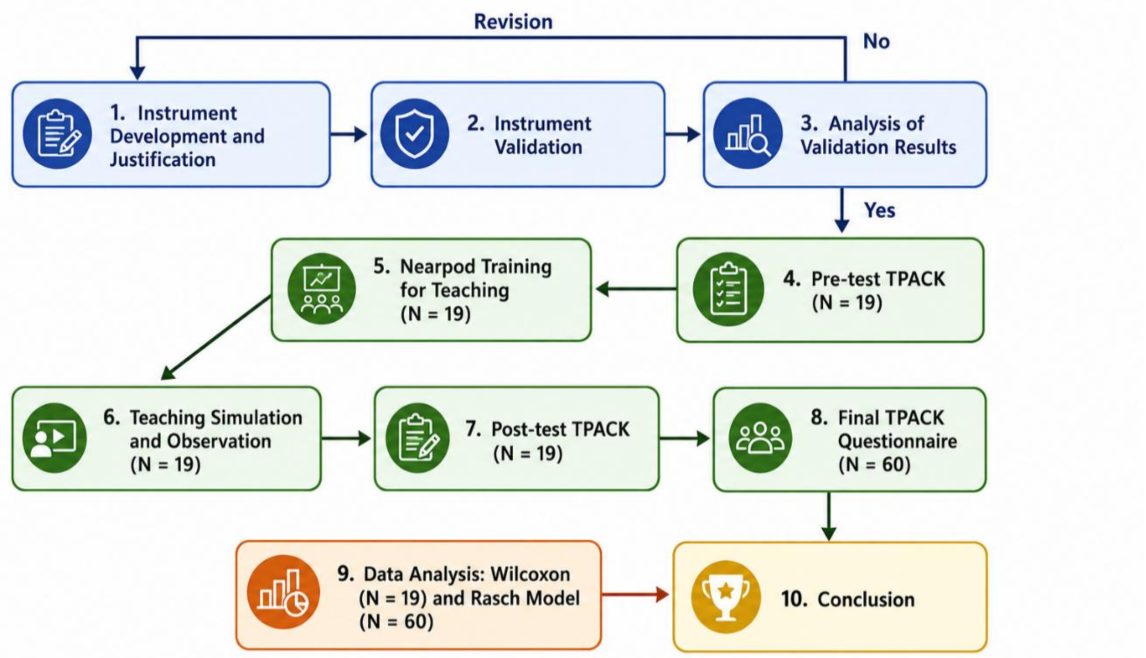

Figure 1. Research Flowchart

The TPACK test comprised 35 questions, while the TPACK questionnaire consisted of 40 statements. Both instruments were developed by adapting the TPACK instrument frameworks developed by (Aumann et al., 2023) and (Destiana et al., 2021), which comprise seven main components: Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK), Technological Pedagogical Knowledge (TPK), and Technological Pedagogical Content Knowledge (TPACK). To strengthen the conceptual foundation within the context of pre-service teachers, the instrument also drew upon the studies of (Stinken-rösner et al., 2023), (Sofyan et al., 2023) and Valtonen et al. (2017). Because the pre-test and post-test data were paired and were not assumed to follow a normal distribution, they were analysed using the Wilcoxon signed-rank test (Dehaene et al., 2021). The final TPACK questionnaire data were analysed descriptively and quantitatively using the Rasch Model with the assistance of the Winsteps application to map students' TPACK competency profiles.

RESULTS AND DISCUSSION

Results

1. Pre-test and Post-test Data

Pre-test data on TPACK abilities before training and post-test data on students' TPACK abilities after participating in training on the use of Nearpod in designing learning tools are presented in the following table.

Table 1. Pre-test and Post-test Data on the TPACK Abilities of Prospective Physics Teachers

No	N = 19	Mean	SD	N-Gain	N-Gain Category	N-Gain (%)	Effectiveness	Sig. (2-tailed)
1	Pre-test	76.05	11.11	0.65	Moderate	65,26	effective enough	0.000 ***significantly different***
2	Post-test	91.50	9.53					

Based on the statistical analysis, the mean pre-test score for preservice physics teachers' TPACK was 76.05 (SD = 11.11), whereas the mean post-test score increased to 91.50 (SD = 9.53) after the Nearpod-based training. The N-Gain value of 0.65 (65.26%) indicates a moderate improvement and can be categorized as quite effective. In addition, the significance test at the 95% confidence level produced a Sig. (2-tailed) value of 0.000, confirming a statistically significant difference between the pre-test and post-test scores. These findings indicate that the training contributed positively and significantly to the development of participants' TPACK. This pattern is consistent with the view that TPACK develops more meaningfully when preservice teachers engage in structured opportunities to connect technology, pedagogy, and subject matter in practice rather than learning each component in isolation (Chai & Deng, 2022; Chen et al., 2025; Tondeur et al., 2025).

Importantly, the increase should not be interpreted merely as greater familiarity with a digital application. During the training, participants were required to use Nearpod to organize lesson content, select interactive activities, and develop formative assessment tasks for physics learning. This process demanded the integration of technological knowledge with pedagogical judgment and content considerations. In other words, the improvement in scores suggests that participants began to understand not only how to operate a platform, but also how to use it to represent physics concepts, engage learners, and monitor understanding in a more purposeful way. Such design-oriented experiences are widely recognised as important for strengthening preservice teachers' technology integration competence because they make instructional choices visible and actionable (Hakami, 2020; Howard et al., 2021; Jun-on & Suwanreang, 2026).

2. TPACK Questionnaire Data

The TPACK questionnaire data was analysed using Winstep software with the Rasch Model.

3. Person Measure (TPACK Competency Level of Prospective Physics Teachers)

The TPACK ability level of prospective physics teachers was obtained through person measure data. Person measure data was sorted from highest to lowest ability based on each person's logit value. To determine the grouping of TPACK abilities of prospective physics teacher students, a standard deviation value of 1.42 was used, then the reference point for determining student ability was the average logit value of 1.65. The criteria for grouping student TPACK abilities were as follows.

Table 2. Criteria for Classifying TPACK Competencies of Prospective Physics Teachers

No	Logit Value of TPACK Competence	Category
1	≥ (1.65 + 1.42) = ≥ 3.07 logit	High
2	between (1.65 – 1.42) and (1.65 + 1.42) = 0.23 until 3.06 logit	Medium
3	< (1.65 – 1.42) = < 0.23 logit	Low

Based on Rasch Model analysis, data on the TPACK ability level of prospective physics teachers was obtained, as shown in the following table.

Table 3. TPACK Competency Level of Prospective Physics Teachers

No	Person	Measure	Category
1	28PUA	9.46	High
2	37PUB	4.53	High
3	24PUA	4.30	High
4	21PUA	3.28	High
5	13PUA	3.08	High
6	36PUB	2.99	Medium
7	50PUC	2.99	Medium
8	40PUC	2.70	Medium
9	59PUB	2.70	Medium
10	44PUC	2.52	Medium
11	35PUB	2.42	Medium
12	26PUA	2.33	Medium
13	25PUA	2.24	Medium
14	58PUB	2.24	Medium
15	23PUA	2.15	Medium
16	27PUA	2.15	Medium
17	53LUC	2.06	Medium
18	01PUA	1.97	Medium
19	10PUA	1.97	Medium
20	34PUB	1.89	Medium
21	49PUC	1.89	Medium
22	55PUD	1.80	Medium
23	22LUA	1.72	Medium
24	02PUA	1.64	Medium
25	30PUB	1.64	Medium
26	46PUC	1.64	Medium
27	52PUC	1.64	Medium
28	12PUA	1.56	Medium
29	51PUC	1.48	Medium
30	17PUA	1.40	Medium
31	41PUC	1.40	Medium
32	38PUB	1.32	Medium
33	43PUC	1.25	Medium
34	09PUA	1.17	Medium
35	32PUB	1.17	Medium
36	20PUA	1.10	Medium
37	39PUC	1.10	Medium
38	45PUC	1.10	Medium
39	57PUC	1.10	Medium
40	60PUC	1.10	Medium

No	Person	Measure	Category
41	06PUA	1.03	Medium
42	54PUD	1.03	Medium
43	29PUB	.96	Medium
44	08PUA	.83	Medium
45	14PUA	.83	Medium
46	18PUA	.83	Medium
47	31PUB	.83	Medium
48	04PUA	.77	Medium
49	16PUA	.77	Medium
50	33PUB	.77	Medium
51	03PUA	.64	Medium
52	05PUA	.64	Medium
53	47PUC	.52	Medium
54	56PUA	.52	Medium
55	48PUC	.46	Medium
56	19PUA	.40	Medium
57	15PUA	-.02	Low
58	42PUC	-.12	Low
59	07PUA	-.17	Low
60	11LUA	-.45	Low

The Rasch analysis showed that 5 respondents (8.3%) were in the high TPACK category, 51 respondents (85%) were in the medium category, and 4 respondents (6.7%) were in the low category. This pattern indicates that most preservice physics teachers had reached an adequate level of TPACK after the training, although only a limited number had developed a highly advanced level of integrative competence. This distribution is noteworthy because it suggests that Nearpod-based training was particularly effective in helping most participants attain a functional level of technology integration. The platform appears to have supported participants in becoming more confident in planning interactive physics lessons, even if not all of them had yet achieved sophisticated integration across pedagogy, content, and technology. Thus, Nearpod may serve as an accessible entry point for preservice teachers to begin developing TPACK in a structured and discipline-relevant manner. This interpretation aligns with previous TPACK scholarship showing that teacher learning often progresses first toward workable integration before reaching fully balanced and advanced TPACK performance (Chai & Deng, 2022; Jin & Schmidt-crawford, 2022).

4. Wright Map (Discrimination Index and Probability Level in Answering Items)

The results of the Wright Map analysis show that respondents' TPACK proficiency ranges from −2 to +7 logits, with the majority falling within the range of 0 to +3 logits. This distribution indicates that most respondents have moderate to high TPACK proficiency. Meanwhile, the difficulty level of the TPACK questionnaire items ranges from −2 to +3 logits with a relatively even distribution. Some of the items, such as PCK2 and PK2, were ranked highest, indicating that these items were the most difficult for respondents to agree with. Conversely, items such as TK1 and TK5 were ranked lowest, indicating that these statements were the easiest for respondents to agree with.

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   Person - MAP - Item
       <more>|<rare>
 7        X  +
             |
             |
             |
 6           +
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             |
             |
 5           +
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          X  |
          X  |
 4           +
             |
            T|
          X  |
 3      XXX  +
         XX  |
         XX S|
      XXXXX  |  PCK2    PK2
 2    XXXXX  +T
     XXXXXX  |  CK3     TPACK3
       XXXX M|  PK5     TCK3    TPK2
       XXXX  |
 1 XXXXXXXX  +S
  XXXXXXXXX  |  TK3
       XXXX S|  PCK5
             |  CK1     PCK4    TPK1    TPK3
 0       XX  +M CK2     PCK3    PK1     PK3     PK4     TPACK2  TPK5
          X  |  TK4     TPACK8  TPK4
          X T|  PCK1    TCK1    TCK4    TCK5    TK2     TPACK4  TPACK6
                TPACK7
             |  CK5     PK6     TCK2
-1           +S CK4     TCK6    TPACK1  TPACK5
             |
             |
             |  TK5
-2           +T TK1
       <less>|<frequ>
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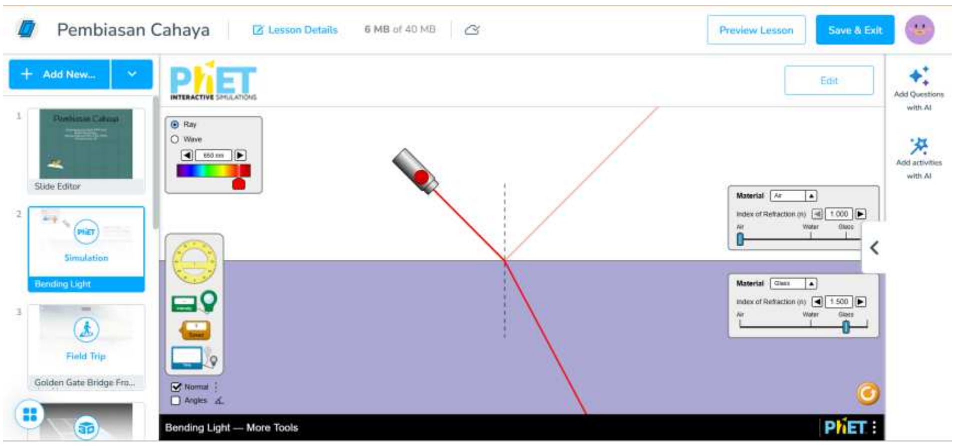
Figure 2. Wright Map

The average respondent ability (+1.65 logits) exceeded the average item difficulty (0 logits), indicating that, overall, participants demonstrated good TPACK mastery. This means that most respondents were able to engage with the combined demands of technology, pedagogy, and content at an adequate level. The questionnaire was therefore effective in capturing variation in TPACK and in showing that the majority of respondents had developed reasonably strong competence. In TPACK terms, this suggests that the intervention was successful not only at the level of isolated technological familiarity, but also at the level of integrative professional knowledge (Kulaksız & Toran, 2022; Tirapicos & Payan-carreira, 2023).

Viewed in relation to the intervention, this result also suggests that Nearpod was sufficiently accessible for participants to focus on instructional decision-making rather than on overcoming technical barriers. Because the platform allows users to present materials, embed questions, and obtain immediate responses within a single lesson flow, participants were able to practise technology integration in a more applied and manageable way. This may explain why the training was able to promote measurable TPACK growth within a relatively short period. Similar findings have been reported in studies emphasising that accessible digital tools and explicit modeling in teacher education can accelerate early-stage technology integration competence (Hakami, 2020; Howard et al., 2021; Tondeur et al., 2025).



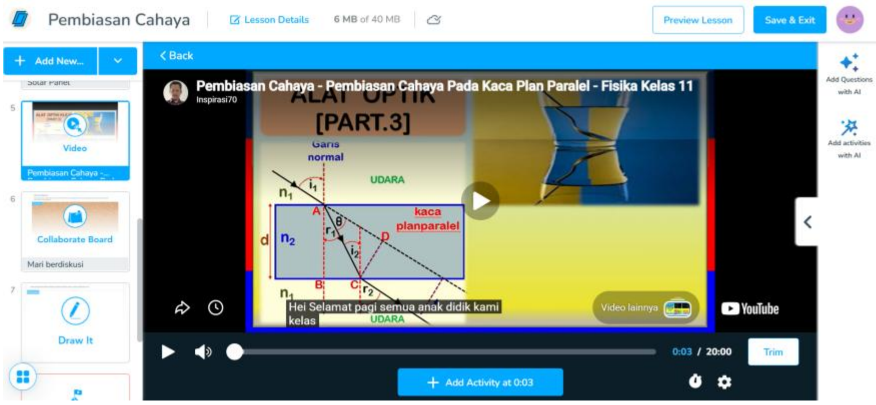


Figure 3. Example of Nearpod Display, Nearpod can be connected to PhET Simulation, YouTube Video, 3D Animation etc.

When examined by TPACK dimension, a more nuanced pattern emerged. In the Technological Knowledge (TK) dimension, items TK1 and TK5 were located at the lowest level (around −2 logits), indicating that respondents generally had little difficulty with basic technology use. However, item TK3, positioned above +1 logit, suggests that some participants still encountered challenges when dealing with more complex technological tasks. In the Pedagogical Knowledge (PK) dimension, item difficulty ranged from −1 to +2 logits, with PK5 and PK6 located at the higher end. This finding indicates that although participants possessed a reasonable pedagogical foundation, they still faced difficulty in applying more adaptive and innovative teaching strategies. In the Content Knowledge (CK) dimension, CK4 and CK5 were relatively easy (around −1 logit), whereas CK3 was more difficult (+2 logits), suggesting that basic content mastery was adequate but depth of understanding still varied across respondents. This gradient across dimensions is in line with research showing that preservice teachers often display uneven TPACK profiles, especially when they move from general technology use toward more content-specific and pedagogically refined applications (Irwanto et al., 2022; Kim et al., 2024; J. Su, 2023).

These patterns are consistent with the characteristics of Nearpod as a digital teaching platform. The relative ease of TK items may reflect the platform's user-friendly interface and familiar presentation-based structure, which lowered the operational threshold for participants. At the same time, the more demanding PK-related items indicate that effective use of Nearpod in physics teaching requires more than procedural skill. Participants still needed to determine how to sequence ideas, choose appropriate representations, and respond to learners' needs during the instructional process. Thus, the findings suggest that Nearpod supported technological access, while pedagogical sophistication remained a developmental area. This distinction is also emphasized in the TPACK literature, which argues that easy access to tools does not automatically result in high-quality pedagogical integration (Chai & Deng, 2022; Valtonen et al., 2023).

In the Pedagogical Content Knowledge (PCK) dimension, item PCK2 had the highest difficulty level (+2 logits), indicating that linking pedagogical strategies to specific physics content was the most challenging aspect for respondents. In the Technological Content Knowledge (TCK) dimension, item difficulty varied from −1 to +2 logits, showing that participants were generally able to use technology to support content delivery, but still needed to improve their ability to adapt digital media to the characteristics of the material. In the Technological Pedagogical Knowledge (TPK) dimension, items ranged from 0 to +2 logits, and the more difficult TPK2 item suggests that some participants had not yet fully mastered the pedagogically appropriate use of technology. Likewise, in the TPACK dimension, item difficulty ranged from −1 to +2 logits, with TPACK3 and TPACK6 emerging as the most difficult items. This indicates that simultaneous integration of technology, pedagogy, and content remained the most advanced and demanding component of respondents' professional knowledge. A similar pattern has been reported in studies on preservice teachers' design work, where balanced integration tends to be harder to achieve than competence in separated domains (Kim et al., 2024; Tschönhens et al., 2024).

A Nearpod-oriented interpretation helps clarify these results. Nearpod offers rich opportunities for TCK and TPK development through features such as interactive quizzes, collaborative boards, multimedia embedding, simulation links, live participation, and immediate feedback. However, the pedagogical value of these features depends on how appropriately they are matched to physics concepts and learning goals. Participants therefore needed to make decisions about which activity format was suitable for conceptual explanation, when formative questioning should be used to uncover misconceptions, and how student responses should inform the next stage of instruction. The comparatively higher difficulty in PCK and full TPACK suggests that participants were still learning to transform physics content into coherent digital pedagogy. In this regard, Nearpod functioned not merely as a delivery tool, but as a practice environment in which preservice teachers began to experiment with integrative instructional design. This interpretation resonates with prior work on Nearpod and on science-teacher professional learning, both of which underscore the value of interactive, feedback-rich, design-based environments for strengthening pedagogically meaningful technology use (Hakami, 2020; Jiang et al., 2026; Mikeska et al., 2022).

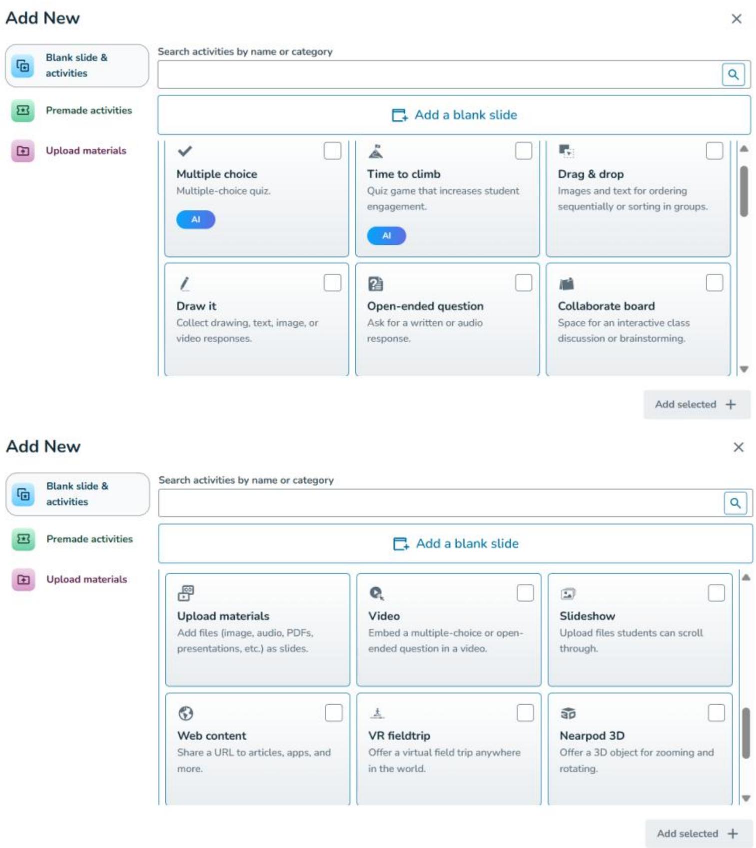


Figure 4. Activity View on Nearpod

Overall, the Wright Map indicates that TK, CK, and parts of PK were relatively easier dimensions for respondents to master, whereas PCK, TPK, and TPACK remained more demanding. This finding suggests that participants had already developed a foundation in the separate domains of technology, pedagogy, and content, but still required support in combining these domains in a coherent way during instruction. Therefore, TPACK-oriented preparation should continue to emphasize integrative design rather than isolated competence in each component. This is consistent with the broader literature, which argues that high-quality technology integration depends on the relationship among domains rather than on mastery of any single domain alone (Chai & Deng, 2022; Tirapicos & Payan-carreira, 2023).

In the context of this study, Nearpod appears to have functioned as a bridge from discrete knowledge domains toward more integrated professional competence. The platform enabled participants to move beyond simply knowing physics content or pedagogical principles and to begin exploring how both can be enacted through digital interaction. Even so, the findings also show that TPACK development is gradual. A short training program can initiate substantial progress, but repeated lesson design, reflection, and teaching simulation are still needed for preservice teachers to use Nearpod in a fully pedagogically and conceptually robust way. Such a staged progression has also been noted in research on teacher education, where modeling, authentic design tasks, and reflective enactment are identified as key supports for durable TPACK growth (Howard et al., 2021; Tondeur et al., 2025).

Discussion

The findings of this study indicate that Nearpod-based training contributed positively to the development of preservice physics teachers' TPACK. The mean score increased from 76.05 in the pre-test to 91.50 in the post-test, with an N-Gain of 0.65, indicating a moderate improvement and a statistically significant effect. This result suggests that TPACK development becomes more meaningful when preservice teachers are involved in practical, contextual, and design-oriented experiences of integrating technology into subject-specific instruction, rather than merely receiving conceptual information about educational technology (Heine et al., 2024; Humaera et al., 2024).

In this study, Nearpod served as an instructional design environment that allowed participants to experience technology integration in a concrete and structured way. The platform enables users to combine interactive slides, embedded quizzes, formative assessment, immediate feedback, collaborative activities, multimedia resources, and flexible pacing within one lesson sequence. These features are particularly relevant in physics education because physics concepts often involve abstract processes, multiple representations, and the need for continuous monitoring of students' conceptual understanding. Therefore, the increase in TPACK scores can be interpreted as evidence that participants were learning not only to use digital tools, but also to connect technological features with the pedagogical and conceptual demands of physics learning (Abdullah et al., 2022; Salvador-Cisneros & Conza-Armijos, 2022).

The Wright Map analysis further showed that respondents' average ability, at +1.65 logits, was higher than the average item difficulty. This indicates that most participants had achieved a relatively solid level of TPACK after the intervention. However, the dimensional pattern shows that Technological Knowledge, Content Knowledge, and parts of Pedagogical Knowledge were relatively easier, whereas Pedagogical Content Knowledge, Technological Pedagogical Knowledge, and holistic TPACK remained more difficult. This pattern suggests that participants were generally ready to use technology operationally, but still required support in determining how technology should be pedagogically deployed for particular physics topics (Fukaya et al., 2024; Zhao & Wang, 2024).

From the perspective of Nearpod use, this finding is understandable. Nearpod is relatively accessible and user-friendly, which may explain the stronger performance on TK-related items. As shown in Figures 3 and 4, Nearpod allows prospective physics teachers to integrate external digital resources, such as YouTube videos and PhET simulations, into a single learning environment. This seamless integration may reduce the technical barriers faced by students when selecting, embedding, and presenting digital learning materials, thereby strengthening their Technological Knowledge (TK). However, effective use of Nearpod in physics instruction requires more than inserting quizzes, videos, simulations, or presentation slides. Teachers need to decide when interactive questioning should be used to diagnose misconceptions, when visualizations and simulations should support conceptual explanation, and how collaborative activities should be organized to deepen students' understanding. These instructional decisions belong to the domains of TPK and TPACK, which require higher levels of pedagogical reasoning and content transformation (Diamah et al., 2022; Yue et al., 2024).

The high difficulty of PCK2 is particularly important because it shows that the main challenge faced by respondents was not the technical operation of Nearpod, but the pedagogical transformation of physics content. In physics teacher education, effective teaching requires more than accurate content delivery. It also requires the ability to select appropriate representations, analogies, examples, learning sequences, and assessment strategies that make abstract and complex physics concepts understandable to students. This is consistent with (Aydin-gunbatar & Akin, 2022) concept of Pedagogical Content Knowledge, which emphasizes teachers' ability to transform subject matter into forms that are pedagogically meaningful for learners. Therefore, the position of PCK2 as a difficult item on the Wright Map indicates that prospective physics teachers still experienced difficulty in transforming physics content into teachable forms. This difficulty is pedagogically meaningful because physics concepts often involve invisible processes, mathematical relationships, and abstract representations, which require careful instructional design rather than simple explanation (Schiering et al., 2022; Wulandari et al., 2024).

The difficulty of holistic TPACK further suggests that integrating technology, pedagogy, and physics content is cognitively demanding for prospective teachers. When designing Nearpod-based physics learning, participants were required to understand the physics content, determine how the content should be represented digitally, select appropriate interactive activities, decide how simulations or visualizations should support conceptual understanding, and provide feedback during learning. These simultaneous decisions may increase cognitive load because prospective teachers must coordinate content knowledge, pedagogical reasoning, technological affordances, and students' possible misconceptions at the same time (Junker et al., 2025; Priyanda et al., 2025). In the TPACK framework, such integration requires teachers to move beyond separate knowledge of technology, pedagogy, and content toward the ability to design coherent technology-enhanced learning experiences (Brianza et al., 2024; Petko et al., 2024). Thus, the difficulty of PCK2 and holistic TPACK indicates that integrated digital pedagogy represents a more advanced stage of professional growth for preservice physics teachers.

This interpretation clarifies the main contribution of the present study. The findings show that Nearpod can function not only as a digital presentation tool, but also as a pedagogical design space that supports the development of preservice physics teachers' TPACK. Through Nearpod-based training, participants were encouraged to connect physics content, digital representation, interactive learning activities, formative assessment, and feedback within a single instructional design. In this sense, Nearpod helped make the process of technology integration more visible and practice-based. At the same time, the Wright Map results revealed which dimensions of TPACK were relatively well developed and which dimensions still required further pedagogical support. This provides a more nuanced understanding of TPACK development by showing that technological fluency does not automatically lead to pedagogically meaningful technology integration (Max et al., 2023; Sofwan et al., 2023).

The practical implication of this finding is that TPACK training for preservice physics teachers should not focus only on introducing digital platforms or demonstrating technical features. Training should also include structured modeling, guided lesson design, peer discussion, reflective evaluation, and repeated opportunities to redesign physics lessons using digital tools. In the context of Nearpod implementation, preservice teachers need to be guided to select digital features based on clear pedagogical purposes, such as diagnosing misconceptions, supporting conceptual visualization, encouraging student interaction, providing formative feedback, and connecting abstract physics concepts with meaningful learning experiences. Therefore, Nearpod-based learning activities should be designed not merely to make lessons more interactive, but to strengthen the alignment among physics content, pedagogy, technology, and assessment.

Overall, the findings provide empirical support for the use of Nearpod as a pedagogically meaningful platform for strengthening preservice physics teachers' TPACK. The intervention improved participants' readiness to design more interactive and technology-supported physics lessons. More importantly, this study demonstrates that Nearpod can support preservice teachers in moving from technical technology use toward more integrated digital pedagogy. Nevertheless, the findings also show that full TPACK mastery remains developmental. Technical and content-related aspects were relatively well established, while pedagogical integration involving technology still required more deliberate scaffolding, reflective practice, and repeated design experience (Baran et al., 2019; Zhang, 2022).

Implications

These findings imply that Nearpod should be positioned in teacher education not merely as an optional digital application, but as a structured environment for cultivating TPACK in subject-specific contexts. Its integration into courses such as lesson planning, microteaching, instructional media development, and physics teaching practice can provide preservice teachers with authentic opportunities to design, implement, and evaluate technology-supported learning activities.

For physics teacher education, Nearpod-based training can help preservice teachers practise transforming physics content into teachable digital experiences. Through interactive questions, simulations, multimedia explanations, and formative assessment, participants can learn to think about what content should be presented, how it should be represented, how students should be engaged, and how understanding should be checked. This process is essential for developing stronger connections among content, pedagogy, and technology.

The findings also imply that teacher education programs should not stop at introducing digital tools. Preservice teachers need structured opportunities to reflect on the pedagogical purpose of each technological feature. For example, quizzes should not only be used to make lessons more interactive, but also to diagnose misconceptions; simulations should not only visualise concepts, but also support inquiry and conceptual reasoning; and collaborative boards should not only increase participation, but also encourage explanation, argumentation, and peer learning.

Research contribution

This study contributes to the literature by providing empirical evidence on the effectiveness of Nearpod-based training in improving preservice physics teachers' TPACK. The use of pre-test, post-test, N-Gain, and Wright Map analysis offers a more comprehensive picture of how participants' TPACK developed after the intervention. Another contribution of this study lies in its subject-specific focus. While many studies discuss technology integration in general teacher education contexts, this study highlights how Nearpod can support TPACK development in physics education. This is important because physics learning has specific pedagogical demands, such as abstract concept representation, visualization of invisible processes, mathematical interpretation, and formative monitoring of conceptual understanding.

This study also contributes by showing that improvements in TPACK are not evenly distributed across all dimensions. Participants showed stronger performance in technological and content-related aspects, but still faced difficulties in PCK, TPK, and holistic TPACK. This finding provides a more nuanced understanding that successful digital training should not only improve technical readiness, but also strengthen pedagogical decision-making and content transformation.

Limitations

This study has several limitations. First, the research was conducted with a specific group of preservice physics teachers, so the findings may not be fully generalisable to broader teacher education contexts or different subject areas. Second, the intervention focused on Nearpod as the main platform, meaning that the results may reflect the affordances of this particular tool rather than technology integration practices in general. Third, although the study showed significant improvement in TPACK scores, the measurement was mainly based on test results and Wright Map analysis. Further evidence from classroom observation, lesson plan analysis, teaching simulation, or reflective journals would provide a richer understanding of how participants actually applied their TPACK in instructional practice. Fourth, the duration of the training may have influenced the depth of TPACK development. Since PCK, TPK, and full TPACK require repeated practice and reflection, a longer intervention might produce stronger and more stable development in these more complex dimensions.

Suggestions

Future studies are suggested to involve a larger and more diverse sample of preservice teachers from different institutions or subject areas. This would help determine whether Nearpod-based training produces similar effects across different educational contexts. Future research should also combine quantitative measurement with qualitative data, such as interviews, teaching portfolios, lesson plan analysis, and microteaching observation. These data would make it possible to examine not only whether TPACK improves, but also how preservice teachers make pedagogical decisions when integrating Nearpod into physics instruction.

Teacher education programs are also encouraged to integrate Nearpod-based design tasks with reflective feedback, peer discussion, and teaching simulation. This combination can help preservice teachers move from functional use of technology toward pedagogically principled use. In particular, training should focus more strongly on PCK, TPK, and TPACK dimensions by guiding participants to design activities that address misconceptions, support conceptual change, and connect digital interaction with physics learning objectives. Finally, future interventions may compare Nearpod with other interactive platforms to examine whether different digital tools produce different patterns of TPACK development. Such comparative studies would provide deeper insight into how specific technological affordances influence preservice teachers' pedagogical reasoning and professional growth.

CONCLUSION

This study concludes that Nearpod-based training in the design of physics learning tools had a positive and significant effect on improving preservice physics teachers' TPACK. The increase in participants' scores indicates that the training was effective in strengthening their ability to integrate technology, pedagogy, and physics content in instructional design. The Wright Map analysis further showed that participants demonstrated relatively strong mastery of Technological Knowledge, Content Knowledge, and several aspects of Pedagogical Knowledge. However, the dimensions of Pedagogical Content Knowledge, Technological Pedagogical Knowledge, and holistic TPACK still required further strengthening. These findings suggest that while preservice physics teachers may be able to operate digital tools and understand physics content, they still need more structured support in transforming physics concepts into meaningful technology-enhanced learning experiences.

The main contribution of this study lies in showing that Nearpod can serve not only as a digital learning platform, but also as a pedagogical design space for developing preservice physics teachers' TPACK. Through Nearpod-based training, participants were encouraged to connect physics content, interactive digital features, formative assessment, student engagement, and feedback within an integrated learning design. Therefore, the use of Nearpod has practical implications for physics teacher education, particularly in helping preservice teachers design interactive, conceptually meaningful, and pedagogically aligned digital physics lessons.

Based on these findings, physics education study programs are recommended to integrate learning technologies such as Nearpod more systematically into courses related to lesson planning, instructional media, assessment, and microteaching. Training should not only focus on the technical use of digital platforms, but also provide guided practice, modeling, reflection, and repeated design experiences that help preservice teachers strengthen the PCK, TPK, and TPACK dimensions. Future studies are recommended to involve a larger number of participants, extend the duration of training, and examine the implementation of Nearpod-based TPACK development across different physics topics or broader science learning contexts. Qualitative data, such as interviews, observations, or analysis of lesson designs, may also be used to gain deeper insight into the challenges faced by preservice teachers in integrating technology, pedagogy, and content.

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AUTHOR CONTRIBUTION STATEMENT

MY contributed to the conceptualization, research design, methodology, supervision, and manuscript review. MP contributed to the methodology, data analysis, validation, and manuscript writing. CH contributed to research supervision, interpretation of findings, and manuscript review. MU contributed to data collection, research implementation, and preparation of supporting materials. AL contributed to data collection, documentation, and assistance in research implementation. All authors have read and approved the final version of the manuscript.

AI DISCLOSURE STATEMENT

The authors used ChatGPT during the preparation of this work only for language refinement, grammar checking, and improving the clarity of expression. The authors thoroughly reviewed, verified, and edited all content and take full responsibility for the content of the publication.

CONFLICTS OF INTEREST

The authors declarethat they have no conflict of interest.

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