

RESEARCH ARTICLE

Digital Proficiency and Educational Technology Use as Predictors of Elementary and Secondary Teachers' AI-TPACK

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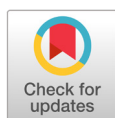
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ABSTRACT

This study examined the relationships of elementary and secondary teachers' digital proficiency, frequency of educational technology use, and average daily digital device use with artificial intelligence technological pedagogical content knowledge (AI-TPACK). It also examined whether these variables predicted overall AI-TPACK and whether digital proficiency and AI-TPACK differed by school level. Data from 139 elementary and secondary teachers and education specialists who completed an online survey were included in the final analysis. AI-TPACK was assessed using a 27-item self-report instrument covering five domains. Digital proficiency, average daily digital device use, and frequency of educational technology use were also measured using self-report items. The data were examined through descriptive statistics, mean comparisons using independent-samples t tests, bivariate Pearson correlations, and a multiple regression model. Digital proficiency and frequency of educational technology use were positively associated with all AI-TPACK domains and overall AI-TPACK. Both variables significantly predicted overall AI-TPACK, with digital proficiency showing the larger standardized coefficient. In contrast, average daily digital device use was weakly associated only with AI technological knowledge (AI-TK) and did not significantly predict overall AI-TPACK. The regression model explained 39.6% of the variance in overall AI-TPACK. Elementary participants reported higher digital proficiency and higher scores on the integrated AI-TPACK domain than secondary participants. No significant school-level differences were found in overall AI-TPACK or the other domains. Descriptively, AI-Ethic had the lowest mean score among the AI-TPACK domains. These findings suggest that AI-TPACK is more closely related to understanding digital technologies and applying them in educational contexts than to general device use. Teacher education and professional development should emphasize purposeful instructional application, pedagogical integration, and the ethical use of AI technologies.

Keywords: AI-TPACK, digital proficiency, educational technology use, digital device use, teacher competence, artificial intelligence education



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Introduction

The use of digital technologies, including artificial intelligence (AI), is increasing in educational settings. AI can support personalized learning, analyze learning processes, and provide feedback based on learners' needs and abilities (Caspari-Sadeghi, 2026; Lee, 2026). AI-based tools are also used to develop instructional materials, design lessons, and support student learning (MacDowell et al., 2024). However, technology alone does not guarantee meaningful educational outcomes. Teachers must understand AI and use it appropriately in instruction (Caspari-Sadeghi, 2026). Research is therefore needed to understand and support teachers' capacity to use AI in education.

Technological Pedagogical Content Knowledge (TPACK) is a widely used framework to explain teacher technology integration (Mishra & Koehler, 2006). TPACK emphasizes technological knowledge, pedagogical knowledge, content knowledge, and interactions between these domains. It describes how teachers integrate technology into subject-specific instruction. As the educational use of AI has expanded, increasing attention has been paid to competencies that extend beyond general technology integration. Teachers must understand the characteristics of AI and apply it appropriately to teaching and learning.

Celik (2023) extended the TPACK framework to AI-based educational contexts and proposed the AI-TPACK framework. AI-TPACK includes knowledge of AI technologies and the ability to integrate AI with pedagogy and subject matter. It also includes the capacity to ethically use AI in educational settings (Byeon & Kwon, 2026; Shin & Paik, 2025). AI-TPACK thus provides a framework for examining the competencies teachers need to design and implement AI-supported instruction.

Recent studies have used AI-TPACK to examine teachers' competencies for AI integration. AI education programs have been found to improve preservice teachers' AI-TPACK (Shin & Paik, 2025). Other studies have examined differences in teachers' AI-TPACK across subject areas (Byeon & Kwon, 2026). AI-TPACK has also been associated with teachers' intentions to use AI and their acceptance of AI technologies (Wang & Li, 2026). In addition, teachers' AI-related competencies may be related to their experience, self-efficacy, and institutional support (Ergun & Arslan, 2026). However, previous research has focused mainly on measuring AI-TPACK or evaluating the effects of professional development programs. The factors that contribute to teachers' AI-TPACK have received comparatively little empirical attention.

Digital technology has also become increasingly important in science education. Science instruction using digital inquiry tools may support students' information-processing competencies and collaborative problem-solving skills (Jeong & Son, 2020). Mobile inquiry learning and science instruction using augmented and virtual reality have also been implemented (Byun & Park, 2023; Kim & Kang, 2025). In Korea, the 2022 revised national curriculum identifies digital literacy as a foundational competency and emphasizes the use of digital technologies in teaching and learning (Ministry of Education, 2022). These changes increase the need for teachers who can integrate digital technologies into science instruction.

Research on teachers' digital competence has been conducted mainly in the fields of educational technology and information education. Recent studies have developed instruments to measure teachers' competence in using digital technologies, including AI (Heo et al., 2024). Other studies have proposed competency frameworks and behavioral indicators for teachers' AI and digital competence (Shin et al., 2023). The competencies required for AI-supported education have also been identified (Lee et al., 2022). These studies show that digital competence extends beyond

technical skills. It includes instructional design, problem solving, ethical use, and professional learning.

However, most previous studies have focused on developing competency frameworks or measurement instruments. The relationship between teachers' digital competence and AI-TPACK has not been sufficiently examined across elementary and secondary educational contexts, including science education. Moreover, knowledge of and familiarity with digital technologies do not necessarily lead to their use in instruction. Teachers' repeated and intentional use of digital technologies may contribute to their confidence and instructional strategies. Educational experience with digital tools may therefore be closely related to teachers' technology integration competence (Byeon & Kwon, 2026).

General digital competence and educational use experience should be examined as distinct but related factors. In this study, digital proficiency refers specifically to teachers' self-reported understanding of hardware and software and their proficiency in using digital devices and software applications. Educational use experience reflects their actual use of these technologies for instructional purposes. Both factors may be associated with teachers' ability to integrate AI into teaching. However, few empirical studies have examined whether these factors are related to or predict teachers' AI-TPACK across different school levels and instructional contexts.

This study examined the relationships of teachers' average daily digital device use, digital proficiency, and frequency of educational technology use with AI-TPACK. It also investigated the extent to which these variables predicted teachers' overall AI-TPACK. Differences in digital proficiency and AI-TPACK by school level were also examined. The following research questions guided the study:

1. How are teachers' average daily digital device use, digital proficiency, and frequency of educational technology use related to AI-TPACK?
2. To what extent do teachers' average daily digital device use, digital proficiency, and frequency of educational technology use predict overall AI-TPACK?
3. Are there differences in digital proficiency and AI-TPACK between elementary and secondary school-level participants?

Research Methods

Participants

A total of 142 participants completed the survey. After excluding responses from secondary teachers who did not specialize in science education and incomplete responses, 139 participants were included in the final analysis (Table 1). The sample comprised 43 elementary-level and 96 secondary-level participants, including six education specialists—three from each school level—who were classified according to their previous teaching level. Elementary teachers teach science as part of a multi-subject curriculum regardless of their academic specialization, whereas the secondary teachers specialized in science education. Participants were recruited through teacher group chats and professional development programs. The online survey was conducted over two weeks in December 2025. All participants received information about the study and provided informed consent before completing the survey.

Table 1. General characteristics of participants

Characteristics	Category	N(%)
School level	Elementary	43(30.9)
	Secondary	96(69.1)
Professional role	Teacher	133(95.7)
	Education specialist—elementary background	3(2.2)
	Education specialist—secondary background	3(2.2)
Educational career	≤10 years	16(11.5)
	11–15 years	39(28.1)
	16–20 years	43(30.9)
	21–25 years	22(15.8)
	≥26 years	19(13.7)
Total		139(100)

Instruments

Teachers' AI-TPACK was measured using the instrument employed by Byeon and Kwon (2026). The instrument consisted of 27 items across five domains: AI technological knowledge (AI-TK), AI technological pedagogical knowledge (AI-TPK), AI technological content knowledge (AI-TCK), AI ethics (AI-Ethic), and AI technological pedagogical content knowledge (AI-TPACK). Each item used a 7-point Likert-type response format anchored at 1 (strongly disagree) and 7 (strongly agree); higher composite scores reflected greater self-reported AI-TPACK.

Digital proficiency was measured using three self-report items from Byeon and Kwon (2026). The items assessed participants' understanding of hardware, understanding of software, and proficiency in using digital devices and software applications. Responses were provided on an 11-point scale ranging from 0 to 10, and the three items were averaged to yield a composite digital proficiency score, with higher values reflecting greater proficiency. The three items showed high internal consistency in this study (Cronbach's $\alpha = .918$).

Participants reported their average daily digital device use, including mobile devices and computers. Daily use time was measured using four ordered categories: 1–3 hours, 4–6 hours, 7–9 hours, and 10 hours or more. Participants also reported whether they had used digital devices or software for educational activities, the types of activities in which they had used them, and their frequency of educational technology use. Types of educational activities included classroom instruction, extracurricular club activities, and camps or lectures. Frequency of educational technology use was measured using seven categories ranging from none to every class.

Data Analysis

The statistical analyses were conducted with IBM SPSS Statistics (version 27.0). Frequencies and descriptive statistics were calculated to summarize participants' demographic characteristics and patterns of digital technology use. Internal-consistency reliability of each measure was evaluated using Cronbach's α . School-level differences in digital proficiency and AI-TPACK were tested with independent-samples *t* tests. The ordered categories of average daily digital device use and frequency of educational technology use were coded in ascending order for subsequent analyses. Pearson correlation analyses were conducted to examine the relationships of average daily digital device use, digital proficiency, and frequency of educational technology use with the AI-TPACK domains and overall AI-TPACK. Multiple regression

analysis was conducted to examine whether average daily digital device use, digital proficiency, and frequency of educational technology use predicted overall AI-TPACK. Tolerance values and variance inflation factors were examined to assess multicollinearity.

Results

Descriptive statistics and internal-consistency reliability estimates for the study variables are summarized in Table 2. The mean score for digital proficiency was 6.89, and the mean overall AI-TPACK score was 5.09. Among the AI-TPACK domains, AI-TK had the highest mean score (5.42), whereas AI-Ethic had the lowest mean score (4.60). Cronbach's α ranged from .906 to .981, indicating high internal consistency.

Table 2. Descriptive statistics and reliability of the scales

Scale	Number of items	<i>M</i>	<i>SD</i>	Cronbach's α
Digital proficiency	3	6.89	1.714	.918
AI-TK	5	5.42	1.058	.939
AI-TPK	7	5.24	1.063	.928
AI-TCK	4	5.26	1.193	.915
AI-TPACK	7	4.91	1.440	.977
AI-Ethic	4	4.60	1.315	.906
Overall AI-TPACK	27	5.09	1.111	.981

Teachers' patterns of digital technology use are shown in Table 3. The most commonly reported category of average daily digital device use was 4–6 hours, reported by 58 participants (41.7%). This was followed by 7–9 hours, reported by 32 participants (23.0%); 1–3 hours, reported by 25 participants (18.0%); and 10 hours or more, reported by 24 participants (17.3%). For frequency of educational technology use, the modal category was once per week, chosen by 59 participants (42.4%). This was followed by 2–3 times per week, reported by 31 participants (22.3%), and 4–5 times per week, reported by 21 participants (15.1%).

Table 3. Characteristics of digital use

Characteristics	Category	<i>N</i>	%
Average daily digital device use	1–3 hours	25	18.0
	4–6 hours	58	41.7
	7–9 hours	32	23.0
	10 hours or more	24	17.3
	None	9	6.5
Frequency of educational technology use	Intensive use during a semester	7	5.0
	Once a month	10	7.2
	Once a week	59	42.4
	2–3 times per week	31	22.3
	4–5 times per week	21	15.1
	Every class	2	1.4

School-level differences in digital proficiency and AI-TPACK are reported in Table 4. Elementary teachers reported significantly higher digital proficiency than secondary teachers, $t(137) = 2.722, p = .007$. Elementary teachers also had a significantly higher mean score on the AI-TPACK domain, which reflects the integrated use of technological, pedagogical, and content knowledge, $t(137) = 1.986, p = .049$. No significant differences were found for AI-TK, AI-TPK, AI-TCK, AI-Ethic, or overall AI-TPACK.

Table 4. Differences in digital proficiency and AI-TPACK by school level

Variables	Elementary		Secondary		<i>t</i>	<i>p</i>	Cohen's <i>d</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>			
Digital proficiency	7.47	1.47	6.63	1.76	2.722	.007	.499
AI-TK	5.56	0.86	5.35	1.13	1.051	.295	.193
AI-TPK	5.46	0.87	5.14	1.13	1.635	.104	.300
AI-TCK	5.53	1.00	5.14	1.26	1.801	.074	.331
AI-TPACK	5.27	1.34	4.75	1.46	1.986	.049	.364
AI-Ethic	4.89	1.15	4.47	1.37	1.746	.083	.320
Overall AI-TPACK	5.34	0.94	4.97	1.17	1.830	.069	.336

Relationships Between Digital Variables and AI-TPACK

Table 5 presents the correlations among average daily digital device use, digital proficiency, frequency of educational technology use, and AI-TPACK. Average daily digital device use showed a weak positive correlation with AI-TK, $r = .187, p < .05$, but was not significantly correlated with overall AI-TPACK. Digital proficiency was positively correlated with all AI-TPACK domains and overall AI-TPACK. Its correlation with overall AI-TPACK was $r = .567, p < .01$. Frequency of educational technology use was also positively correlated with all AI-TPACK domains and overall AI-TPACK. Its correlation with overall AI-TPACK was $r = .467, p < .01$.

Table 5. Correlations among average daily digital device use, digital proficiency, frequency of educational technology use, and AI-TPACK

Variables	AI-TK	AI-TPK	AI-TCK	AI-TPACK	AI-Ethic	Overall AI-TPACK
Average daily digital device use	.187*	.140	.111	.092	.116	.137
Digital proficiency	.567**	.550**	.521**	.497**	.476**	.567**
Frequency of educational technology use	.409**	.473**	.434**	.459**	.364**	.467**

*: $p < .05$, **: $p < .01$

Predictors of Teachers' AI-TPACK

To identify unique contributions of each digital variable to overall AI-TPACK, a simultaneous-entry multiple regression model was estimated. Table 6 presents the results. The regression model was statistically significant, $F(3, 135) = 29.521, p < .001$, and explained 39.6% of the variance in overall AI-TPACK, $R^2 = .396$. The adjusted R^2 was .383. Digital proficiency significantly predicted overall AI-TPACK, $\beta = .460, p < .001$. Frequency of educational technology use was also a significant predictor, $\beta = .296, p < .001$. In contrast, average daily digital device use was not a significant predictor, $\beta = -.021, p = .765$. Tolerance values ranged from .818 to .934, and VIF values ranged from 1.070 to 1.223. These values indicated no multicollinearity concerns. The Durbin-Watson statistic was 1.903, indicating that the residuals were independent.

Table 6. Multiple regression analysis predicting overall AI-TPACK

Predictors	B [95% CI]	SE	β	<i>t</i>	<i>p</i>	Tolerance	VIF
Constant	2.300 [1.641, 2.960]	.333	-	6.900	< .001	-	-
Average daily digital device use	-.024 [-.179, .132]	.079	-.021	-2.299	.765	.934	1.070
Digital proficiency	.298 [.204, .393]	.048	.460	6.222	< .001	.818	1.223
Frequency of educational technology use	.246 [.127, .365]	.060	.296	4.088	< .001	.854	1.170

$R = .629$, $R^2 = .396$, Adjusted $R^2 = .383$, $F(3, 135) = 29.521$, $p < .001$, Durbin-Watson = 1.903

Discussion

The findings distinguish digital proficiency and educational technology use from general device use in their associations with teachers' AI-TPACK. Digital proficiency and frequency of educational technology use predicted overall AI-TPACK, whereas average daily digital device use did not. Within the regression model, digital proficiency had the largest standardized regression coefficient among the three predictors of overall AI-TPACK. As operationalized in this study, digital proficiency reflected teachers' understanding of hardware and software and their proficiency in using digital devices and software applications. The finding therefore suggests that AI-TPACK is associated not only with the frequency of technology use but also with foundational digital knowledge and skills. Because AI-TPACK requires teachers to integrate knowledge of AI technologies, pedagogy, subject matter, and ethical use (Celik, 2023), digital proficiency may support the selection and integration of AI tools in ways that align with instructional goals. Consistent with the present findings, Hava and Babayiğit (2025) reported that teachers' digital proficiency significantly predicted their AI-TPACK competencies. More broadly, teacher digital competence has been conceptualized as a multidimensional construct that extends beyond technical proficiency to encompass pedagogical, ethical, sociocultural, and professional dimensions (Falloon, 2020; Heo et al., 2024; Shin et al., 2023).

Frequency of educational technology use remained a significant predictor of overall AI-TPACK after controlling for digital proficiency and average daily digital device use. It was also positively associated with all AI-TPACK domains. This pattern suggests that teachers who use digital tools more frequently for educational purposes tend to report higher levels of AI-TPACK. However, exposure to or familiarity with digital technologies alone may not lead to effective instructional integration. Teachers must select appropriate tools and align their use with subject matter, pedagogical strategies, and learning objectives. Repeated engagement in this process may provide opportunities to develop technology integration competence. This interpretation is consistent with previous research linking practical experience with digital tools to TPACK and AI-TPACK (Byeon & Kwon, 2026). A synthesis of 19 qualitative studies also identified the alignment of theory and practice, reflection on the role of technology in education, peer collaboration, and scaffolded authentic technology experiences as key strategies for preparing preservice teachers to integrate technology effectively (Tondeur et al., 2012). Also, AI-TPACK may be relevant to teachers' willingness to use AI in instruction. In a structural model involving 291 preservice teachers, AI-TPACK significantly predicted behavioral intention to engage in AI-assisted teaching (Wang & Li, 2026). Taken together, digital proficiency and frequency of educational technology use appear to represent related but distinct factors: the former reflects foundational digital understanding and skills, whereas the latter reflects opportunities to apply technology in educational contexts.

In contrast, average daily digital device use did not significantly predict overall AI-TPACK. This finding suggests that spending more time using digital devices alone may not be associated with higher levels of AI-TPACK. Daily device use may encompass lesson preparation, information searches, administrative tasks, communication, and leisure activities. Although such activities may increase familiarity with digital technologies, they do not necessarily reflect the ability to integrate AI with pedagogy and subject matter. The weak positive association between average daily digital device use and AI-TK suggests that general device use may be related to familiarity with AI technologies but not necessarily to integrated teaching competence. A related pattern was reported in a survey of 122 preservice science teachers, in which prior AI training was associated with higher technological knowledge but not with corresponding gains in pedagogical or content-related competencies (Ergun & Arslan, 2026). Thus, AI-TPACK appears to be more closely associated with digital proficiency and the instructional use of technology than with the amount of time spent using digital devices.

The school-level comparison revealed only limited differences. Elementary teachers reported higher digital proficiency and higher scores in the integrated AI-TPACK domain than secondary teachers. However, no significant school-level differences were found in overall AI-TPACK, AI-TK, AI-TPK, AI-TCK, or AI-Ethic. The difference in the integrated AI-TPACK domain may be related to the elementary teaching context, in which teachers typically coordinate instruction, assessment, and feedback across multiple subjects. This explanation remains tentative, however, because the study did not directly measure instructional organization or opportunities to use digital tools. In addition, the elementary and secondary groups were unequal in size, and potentially relevant factors—including subject specialization, professional roles, AI-related training, and school digital environments—were not controlled. Accordingly, the findings should not be interpreted as evidence that elementary teachers have higher overall AI-TPACK than secondary teachers.

Descriptive statistics across the AI-TPACK domains showed that AI-TK had the highest mean score, whereas AI-Ethic had the lowest. This pattern suggests that participants may have perceived themselves as less confident in understanding and evaluating fairness, bias, the legitimacy of AI-based decision making, and developers' responsibilities than in understanding AI technologies. However, differences in mean scores across the domains were not statistically tested. The pattern should therefore be interpreted as a descriptive tendency rather than as evidence of significant differences among the domains. AI literacy has been conceptualized as encompassing four interrelated dimensions: knowing and understanding AI, using and applying AI, evaluating and creating with AI, and addressing ethical issues (Ng et al., 2021). More specifically, a systematic review identified ethical knowledge, AI transparency and explainability, critical analysis, culturally responsive and inclusive pedagogy, and ethics-related dispositions as interdependent competencies required of K–12 teachers (Tagare et al., 2025). Although descriptive, the relatively low AI-Ethic mean points to a potential need for teacher education to address fairness, bias, transparency, and accountability alongside the functions and instructional uses of AI tools.

The associations observed in this study are consistent with the TPACK framework, which locates effective technology integration in the interplay among technological, pedagogical, and content knowledge (Mishra & Koehler, 2006). MacDowell et al. (2024) similarly emphasized authentic, collaborative, and instructor-guided learning opportunities in preparing teachers to engage with generative AI. These perspectives help explain why digital proficiency and educational technology use may be relevant to AI-TPACK: they concern both understanding technology and applying it within educational contexts. This interpretation also aligns with research emphasizing pedagogical judgment and ethical awareness alongside technical understanding in AI-supported teaching (Caspari-Sadeghi, 2026; Lee et al., 2022).

This study has several limitations. First, all variables were measured using self-report measures and may not fully reflect teachers' actual ability to design and implement AI-supported instruction. Second, digital proficiency was assessed using only three items focused on understanding and using hardware and software. The measure may therefore not capture broader dimensions of digital competence, such as instructional design, problem-solving, ethical use, and professional learning. Third, average daily digital device use and frequency of educational technology use were measured using ordinal categories. The frequency measure also did not capture the specific ways in which digital technologies were used or the quality of their instructional use.

Fourth, the cross-sectional design precludes causal conclusions about the relationships among digital proficiency, frequency of educational technology use, and AI-TPACK. Digital proficiency and educational technology use may be associated with higher AI-TPACK, but teachers with higher AI-TPACK may also be more likely to learn about digital tools and use them more frequently. Fifth, the elementary and secondary groups were unequal in size, and the sample may not represent the broader teacher population. The secondary school participants specialized in science education, whereas the elementary school participants taught science as part of a multi-subject curriculum regardless of their academic specialization. Moreover, because the AI-TPACK instrument did not require participants to respond exclusively with reference to science instruction, elementary and secondary participants may have considered different subject or instructional contexts when responding. This difference limits the interpretation of both the school-level comparison and the results based on the combined sample. Professional roles, AI-related training, and school digital environments were also not controlled. Therefore, the generalizability of the findings is limited, and the school-level results should be interpreted with caution.

Future research should combine self-report measures with classroom observations, analyses of lesson plans and other instructional artifacts, interviews, and performance-based tasks. These methods could clarify the relationship between teachers' self-reported AI-TPACK and their observed ability to implement AI-supported instruction. Longitudinal and intervention studies, including experimental and quasi-experimental designs, are also needed to examine how changes in digital proficiency and educational technology use relate to the development of AI-TPACK and whether teacher education programs can promote such development.

Conclusions and Implications

This study examined the relationships of teachers' digital proficiency, frequency of educational technology use, and average daily digital device use with AI-TPACK. The findings lead to three conclusions and related implications for teacher education.

First, digital proficiency and frequency of educational technology use were significant positive predictors of overall AI-TPACK, whereas average daily digital device use was not. The regression model explained 39.6% of the variance in overall AI-TPACK, with digital proficiency showing the largest standardized coefficient. These findings suggest that teacher education should connect foundational digital knowledge and skills with opportunities for instructional application. Professional development can provide opportunities for teachers to select AI tools aligned with learning goals, design and implement lessons, and evaluate and reflect on their instructional use, rather than focusing solely on tool demonstrations or operational guidance.

Second, school-level differences were limited to digital proficiency and the integrated AI-TPACK domain, in which elementary teachers reported higher scores. No significant differences were found in overall AI-TPACK or the other domains. These findings do not support a general conclusion that one school level possesses higher AI-TPACK. Support for teachers should therefore consider specific competency needs and instructional contexts rather than assume that school level alone determines readiness for AI integration.

Third, AI-Ethic had the lowest descriptive mean among the five domains. Although differences among domain means were not statistically tested, this pattern suggests that ethical understanding warrants attention alongside technological and pedagogical knowledge. Teacher education can incorporate the evaluation of fairness, bias, and accountability into activities involving AI tool selection and lesson design, allowing teachers to consider ethical issues in relation to concrete instructional decisions.

By distinguishing general device use from digital proficiency and educational technology use, this study provides a basis for considering how teacher education can support AI integration. These implications remain subject to the limitations of the self-report measures, cross-sectional design, and sample characteristics, and should be understood as directions for professional development rather than demonstrated effects of particular training approaches.

Conflicts of Interest

The authors declared no conflicts of interest.

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