CJLT RCAT
Canadian Journal of Learning and Technology
La Revue canadienne de l'apprentissage et de la technologie

Volume 50 (4) Special Issue 2024

STEM Teacher Candidates' Preparation for Online Teaching: Promoting Technological and Pedagogical Knowledge

Préparer les futurs enseignants en STIM à enseigner en ligne : comment promouvoir les connaissances technologiques et pédagogiques?

Mohammed Estaiteyeh, *Brock University, Canada*
Isha DeCoito, *Western University, Canada*
Mariam Takkouch, *Western University, Canada*

Abstract

Emergency remote teaching during the COVID-19 pandemic has shed light on pedagogical challenges that require the immediate attention of teacher education programs. This paper focuses on teacher candidates' preparation to teach online in a STEM curriculum and pedagogy course in a teacher education program at a Canadian university. The authors present a two-phase study of two cohorts of teacher candidates enrolled in this course and explore 1) their perceptions of the dynamics and effectiveness of online teaching as a teaching modality, and 2) the impact of the course on their technological and pedagogical skills necessary for online teaching. Quantitative and qualitative data were collected through pre- and post-surveys administered online at the beginning and end of the course. Findings suggest that teacher candidates' engagement with course content resulted in a notable improvement in their views toward online teaching as a teaching modality, pedagogical approaches, and personal abilities utilizing innovative online teaching strategies. This research emphasizes the necessity for comprehensive training programs that enhance teacher candidates' technological competencies while simultaneously refining their pedagogical methodologies for online settings. Implications for teacher education research and practice are discussed.

Keywords: online teaching, STEM teaching, teacher education, TPACK

Résumé

L'enseignement à distance qui a dû s'organiser en urgence lors de la pandémie de COVID-19 a mis en lumière les défis pédagogiques auxquels les enseignants ont été confrontés et la nécessité de modifier dès maintenant les programmes de formation des enseignants. Cet article porte sur la

préparation des étudiants à l'enseignement en ligne dans le cadre d'un cours de deuxième année en STIM et en pédagogie au sein d'un programme de formation des enseignants dans une université canadienne. Les auteurs présentent une analyse en deux phases de deux cohortes d'étudiants en enseignement inscrits à ce cours et explorent 1) leurs perceptions de la dynamique et de l'efficacité de l'enseignement en ligne en tant que modalité d'enseignement, et 2) les répercussions du cours sur les compétences technologiques et pédagogiques nécessaires à l'enseignement en ligne. Des données quantitatives et qualitatives ont été recueillies par le biais d'enquêtes *avant* et *après* effectuées en ligne au début et à la fin du cours. Les résultats montrent que le contenu des cours a permis aux étudiants de renouveler considérablement leur vision de l'enseignement en ligne en tant que modalité pédagogique, leurs approches pédagogiques et leurs capacités personnelles à utiliser des stratégies d'enseignement en ligne novatrices. Cette étude souligne la nécessité de mettre en place des programmes de formation approfondis qui permettent d'améliorer les compétences technologiques des candidats à l'enseignement tout en affinant leurs méthodes pédagogiques dans un contexte d'enseignement en ligne. Nous analysons les implications pour la recherche et la pratique dans le domaine de la formation des enseignants.

Mots-clés: enseignement en ligne, enseignement des STIM, formation des enseignants, TPACK

Introduction

Emergency remote teaching (ERT) is the rapid transition to online teaching based on an urgent resolution to keep instructional continuity with students (Kang et al., 2021). During the COVID-19 pandemic, ERT had significant implications for practice as it highlighted gaps in both teacher candidates' (TCs') and in-service teachers' digital literacy, specifically their confidence, motivation, and competence in using educational technologies in online environments (Burns et al., 2020; DeCoito & Estaiteyeh, 2022b). For instance, research on ERT in Canada highlights challenges facing science, technology, engineering, and mathematics (STEM) teachers, including lack of digital resources and insufficient preparation that negatively affected their teaching and assessment strategies in online settings. Teachers reported their reliance on teacher-centred and less creative strategies as they had to prioritize teaching content with minimal attention to pedagogies (DeCoito & Estaiteyeh, 2022a). Additionally, the 2023 Pan-Canadian report on digital learning trends in Canadian postsecondary education highlights that the expected greater technology integration in teaching and learning raises concerns about faculty skills and know-how to teach in digital environments (Johnson, 2023).

Hodges et al. (2020) explain that ERT implemented hurriedly, with bare minimum resources and limited time must be distinguished from quality online teaching that is based on effective planning and careful instructional design. Hence, educators must now shift their focus to understand the outcomes of this transition and its impact on teachers' competencies in online pedagogy, considering the possibilities associated with current technologies and online resources (Carrillo & Flores, 2020). In harmony, at the level of teacher education programs, the pandemic has created opportunities to reconceptualize online pedagogy as a critical component of teacher preparation (Alvi, 2023).

Research on STEM TCs' preparation in online teaching especially in the Canadian context is limited, despite a few studies that accompanied the pandemic (e.g., Bourgoin, 2023; Tembrevilla &

Milner-Bolotin, 2019; Van Nuland et al., 2020). Given this research gap, and the premise that future teachers must not only be technologically adept but also skilled in digital pedagogy (Aslan & Zhu, 2017), this study addresses teacher preparation for the challenges and opportunities inherent in online learning environments. In this paper, the authors advocate for the necessity for comprehensive training programs that enhance TCs' technological competencies while simultaneously refining their pedagogical methodologies for online settings. The research takes place in a STEM curriculum and pedagogy course in a teacher education program at a university in Ontario. This course was initially developed as a hybrid course, enriched with digital technologies and resources, to support TCs' technological literacy and pedagogical frameworks in STEM education (DeCoito, 2023). However, due to the abrupt pivot to ERT, it was noted that TCs were ambivalent and exhibited anxiety toward online teaching. As such, the STEM course was a preferred context for this research, given that it focuses on curriculum and pedagogy aligned with technological integration, thus offering opportunities for observing the interplay between technology and pedagogy.

Research Questions

The study focuses on TCs' preparation to teach online in a STEM curriculum and pedagogy Year-2 course in a teacher education program at a Canadian university. The authors present a two-phase study of two cohorts of TCs enrolled in this course to explore its impact on TCs' technological and pedagogical skills necessary for online teaching. This paper addresses two research questions:

1. How do TCs perceive online teaching as a teaching modality?
2. What is the impact of the course on TCs' technological and pedagogical skills necessary for online teaching?

Literature Review

Teacher Candidates' Preparation in Online Teaching

The last few years have witnessed an increased adoption of online teaching (Barbour, 2018). Many studies around the world, for instance, in Canada (Burns et al., 2020), United States (Long et al., 2022), Germany (Dilling & Vogler, 2023), Turkey (Bahcivan et al., 2019), South Korea (Han et al., 2017), and UAE (Hojeij & Baroudi, 2021) have demonstrated positive effects of online teaching preparation and training on TCs' and in-service teachers' readiness to engage in this teaching modality. In this section, we describe in detail several interventions from the literature that shed light on the significance of TCs' preparation for online teaching.

A seminal study by Aslan and Zhu (2017) investigated the role of pedagogical training courses in fostering 599 TCs' information and communications technology (ICT) integration. Findings indicated that while TCs demonstrated a positive attitude towards using ICT in their teaching and competence in basic ICT skills (e.g., presentation skills and word processors), they were not competent in integrated ICT skills (e.g., utilizing simulated tasks for experiments). This study concluded that pedagogical knowledge, ICT related courses, and TCs' perceptions were three significant factors predicting TCs' integration of ICT in their teaching, compared to other variables such as attitudes toward technology,

prior ICT experience, and gender. Further, Aslan and Zhu (2017) noted that teacher training programs played a significant role in facilitating TCs' integration of ICT in their teaching and that ICT related courses must consider subject curricula and accompanying pedagogical knowledge. Along the same line, Han et al. (2017) explored technology-centred teaching experiences and their effects on TCs' self-efficacy and intention to use technology. The findings revealed that the technology-centred student experience increased TCs' self-efficacy regardless of their initial beliefs. Han et al. concluded that teachers with traditional pedagogical beliefs significantly benefited from exposure to technology-rich teaching experiences as it encouraged them to integrate technology in their future teaching. Similarly, Dilling and Vogler (2023) examined the impact of a training course in preparing TCs to independently create an online learning unit with Moodle platform. This training was successful in changing the views of TCs especially in creating online content and introducing a topic using the platform, as they found the platform capable of providing individualized support to students through online learning resources. Milner-Bolotin (2019) maintained that TCs and in-service teachers must be given the opportunity to collaboratively design technology-enhanced STEM education resources that are relevant to their teaching contexts. Such resources need to highlight relevant theoretical underpinnings, the evaluation methods for their pedagogical effectiveness, and the purpose of using technology (Milner-Bolotin, 2019).

Collectively, the aforementioned studies outline the critical role of TCs' engagement with online teaching as learners before they utilize it as teachers. However, it is important to note some fundamental factors for the success of such programs. Schubatzky et al. (2023) emphasize that a strong foundation in pedagogical content knowledge (PCK) is essential for the development of TCs' digital media PCK. Additionally, instructors must be cognizant of individual differences among TCs with respect to their experience with digital technologies, and hence must differentiate the training to ensure that TCs are acquiring its benefits relative to their level (Schubatzky et al., 2023).

Teacher Candidates' Pedagogical Views of Online Teaching as a Teaching Modality

During the pandemic, several researchers examined TCs' views of the effectiveness of online teaching as a teaching modality. In Canada for example, studies spanned provinces and territories, including British Columbia (Tembrevilla & Milner-Bolotin, 2019), New Brunswick (Bourgoin, 2023), Alberta (Burns et al., 2020; Burron & Pegg, 2021), Ontario (Van Nuland et al., 2020), and Québec (Raby et al., 2020). On a positive note, online teaching was viewed by TCs as more flexible and adaptable to change than ever before (Coskun Karabulut et al., 2023; Van Nuland et al., 2020). Ali and Nath (2023) argued that online teaching allowed TCs to acquire new skills and knowledge and enhance their ability to self-regulate their learning. In another study, TCs also reported that their technological knowledge was expanded and their ability and confidence in using technological resources increased as they were able to incorporate a variety of online resources in their teaching (Hojeij & Baroudi, 2021). Similarly, Brinia and Psoni (2022) reported that TCs became acquainted with new technologies in education and developed useful skills for their future teaching - including adaptability, flexibility, and managing students' interactions in online settings - that they would not have developed in a traditional setting. Alvi (2023) reported similar findings in which TCs demonstrated improvements in the design (lesson plans), direct instruction (technological skills and methodology), and facilitation of online

teaching (classroom interaction), despite their initial limited beliefs, resistance to change, and unwillingness to engage with technologies.

On the other hand, research findings revealed several challenges reported by TCs in online teaching such as lack of collaboration and interaction with instructors and peers (Ali & Nath, 2023; Margaliot & Gorev, 2020). Additionally, TCs found the online environment to be challenging with respect to individualizing instruction, limiting students' physical movement, and limiting teachers' creativity. Teacher candidates acknowledged their lack of preparation in designing interactive online lessons and highlighted the need for better preparation to incorporate online games, for example, into their instructional practices (Hojeij & Baroudi, 2021). Brinia and Psoni (2022) reported challenges inherent in online teaching in terms of reading students' body language, facilitating group work, and maintaining experiential learning activities. Moreover, TCs indicated a preference for traditional classrooms where they would experience more robust classroom interactions and less pedagogical challenges (Alvi, 2023). Accordingly, Alvi recommended that TCs must be offered training and support to enhance their digital literacy skills and experiment with different teaching approaches and technologies related to their own practice to help them overcome stated challenges. Similarly, Margaliot and Gorev (2020) suggested that online pedagogy courses must create a real need for collaboration between TCs so that they recognize its practical aspects and significance.

Furthermore, Burron and Pegg (2021) reported that TCs were generally inefficient in their searches for online teaching resources. They concluded that TCs required online resources that are complete, provide background and context, and are modifiable, aligned with curriculum outcomes, and provide appropriate pedagogical content knowledge to use the resources effectively. Hence, TCs must be prepared to search for and recognize those resources efficiently, as well as how to construct resources that are useful and organized in a way that is readily accessible (Burron & Pegg, 2021). Despite these challenges, Burns et al. (2020) reported that TCs acknowledged that they require online instructional skills for their future teaching practice, despite their initial thoughts that online instruction is impractical, unrelated to their teaching practice, and just a temporary solution. Hence, Burns et al. concluded that there is a need to consider online pedagogy as a more central part of TCs' education.

Overall, these studies reiterate the need for teacher training programs that promote and enhance technological competencies and pedagogical skills needed for online teaching. These programs must also address TCs' views of online teaching as a teaching modality, especially that such perceptions significantly predict and influence TCs' integration of ICT in their future teaching.

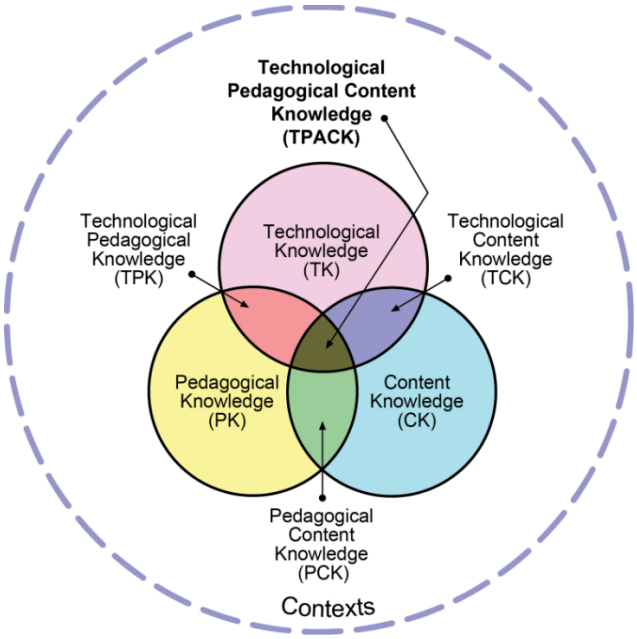
Theoretical Framework

This research is informed by the technological, pedagogical, and content knowledge (TPACK) framework (Mishra & Koehler, 2006) and the digital competencies for teaching in science education (DiKoLAN) framework (Von Kotzebue et al., 2021). Shulman (1987) defines pedagogical content knowledge as the "capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful yet adaptive to the variations in ability and background presented by the students" (p. 15). Mishra and Koehler (2006) extend Shulman's PCK to integrate technology into

teacher's pedagogy. This model of technology integration in teaching and learning is known as TPACK (Koehler et al., 2013) (Figure 1).

Figure 1

TPACK Framework



Note. Reprinted by permission of the publisher from http://tpack.org. © 2012 by tpack.org.

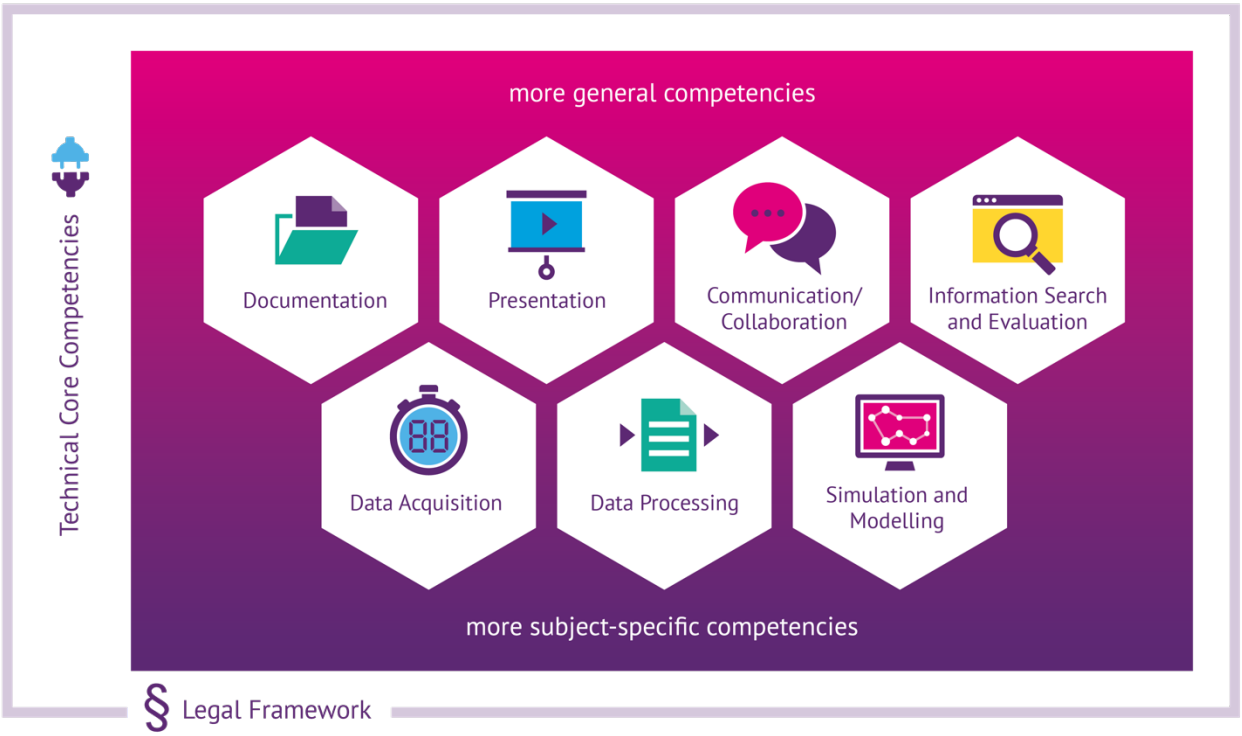
In teacher education programs, TCs may develop their TPACK through dedicated educational technology courses and by incorporating content-specific teaching methods (Hofer & Grandgenett, 2012). Teacher candidates' training plays a significant role in promoting their TPACK self-efficacy (Joshi, 2023) and enhancing their TPACK levels as they connect their content areas, content-specific pedagogies, and available technologies (Tondeur et al., 2020). Joshi (2023) highlights that subject-based professional development practices for integrating technology into the curriculum can support teachers in improving their technology self-efficacy. Thus, such contextualization of technological skills is crucial and provides additional rationale for choosing the STEM curriculum and pedagogy course as a setting for the research study underlying this paper.

On another note, Von Kotzebue (2022) argue that subject-specific description of TPACK has been limited. Hence, they propose a framework that is subject-specific for science TCs to design and implement digitally supported science education. This framework, titled Digital Competencies for Teaching in Science Education (DiKoLAN) is a foundational step towards domain-specific structuring and assessment of TPACK. DiKoLAN includes four general competency areas that are essential for digitally supported teaching in all subjects (documentation, presentation, communication/collaboration, and information search and evaluation) and three science-specific competency areas (data acquisition, data processing, and simulation and modeling) (Figure 2). Additionally, each of the seven competencies is described by competency expectations that are structured with reference to the four technology-related dimensions of the TPACK framework (TPACK, technological pedagogical knowledge- TPK,

technological content knowledge- TCK, and technological knowledge- TK) and three levels of performance (Name, Describe, Use/Apply). Von Kotzebue et al. (2021) recommend utilizing the DiKoLAN framework to guide the creation of science curricula in teacher education as well as evaluating TCs' competency levels and development processes. A few research studies have recently adopted this novel framework (e.g., Henne et al., 2022; Krug et al., 2023; Müller et al., 2022; Schubatzky et al., 2023). Our paper utilizes aspects of the DiKoLAN framework as an extension of the TPACK framework in analyzing the development of TCs' STEM-education pedagogical and technological skills, to better prepare them for online teaching in the future.

Figure 2

DiKoLAN Framework: Workgroup Digital Core Competencies



Note. Reprinted by permission of the publisher from http://dikolan.de/. © 2020 Workgroup Digital Core Competencies.

Methodology

Research Design and Participants

The research adopts a multiple-case study research design (Yin, 2014). Each case is one cohort of TCs enrolled in a STEM curriculum and pedagogy course, in the second year of a teacher education program at a university in Ontario, Canada. Participants in Cohort 1 are 24 TCs who completed the course online in the academic year 2020-2021. Participants in Cohort 2 are 34 TCs who completed the course in a hybrid format (both in-person and online components) in the academic year 2021-2022. All

TCs were in the intermediate-senior division with teachable subjects in one or two STEM disciplines (science, biology, physics, chemistry, health and physical education, and math).

The study occurred in a 12-week curriculum and pedagogy in STEM course in the STEM specialty focus in a teacher education program. The course was designed to promote TCs' use of digital technologies and enhance their preparation in online teaching. For instance, the course offered theoretical and practical lessons on educational technologies and TPACK. Additionally, the online delivery of course components provided opportunities to practice and model online teaching pedagogies. Course assignments focused on creating and incorporating digital technologies in K-12 teaching such as digital timelines (DeCoito & Vacca, 2020), digital case studies, digital video games, and developing digital STEM curriculum websites (DeCoito, 2023). In these assignments, TCs assumed the dual roles of curriculum developers and learners in STEM education to engage with these resources from both perspectives.

Data Sources

Quantitative and qualitative data were collected through pre- and post-surveys administered online to TCs at the beginning and end of the course, respectively. This paper reports on 25 5-point Likert scale statements (1=strong disagreement to 5=strong agreement) in both surveys and two open-ended questions in the post-survey. The survey statements and questions addressed TCs' technological and pedagogical competencies in online teaching, their pedagogical perceptions of online teaching as a teaching modality, and reflections on the effectiveness of the course.

Sample Likert scale items included:

- *I can use more creative teaching methods and ideas when teaching online.*
- *My major concern in online classes is to ensure that the course content is being taught (achieving the curriculum objectives) regardless of the teaching methods.*
- *I find it challenging to integrate student-centred and inquiry-based teaching methods in my online teaching (such as group discussions, online activities and simulations, virtual labs, etc.).*

The two open-ended questions, developed by the research team based on the literature and course activities include:

- *To what extent do you think this course was successful in terms of teaching you specific pedagogical and technological skills to use in online teaching? Reflect on both: the fact that you have learned the course completely online, and the fact that it integrated specific digital components.*
- *List some online teaching skills that you feel need ongoing improvement or more reinforcement despite the material offered in this course.*

Data Analysis

The authors used Qualtrics survey system and Microsoft Excel to analyze the quantitative data resulting TCs' responses to surveys' Likert scale statements. This analysis included calculating counts, averages, standard deviations, percentages, and differences between pre- and post-results. An inductive thematic analysis (Creswell & Creswell, 2018; Schreier, 2013) was conducted to analyze the qualitative data resulting from TCs' responses to the open-ended questions. Two of the researchers collaboratively synthesized initial codes based on the frequency count in TCs' responses. Thereafter, the authors grouped similar codes into themes to draw conclusions (Gall et al., 2005). To ensure the trustworthiness of the analysis (Creswell & Creswell, 2018), the three research team members convened to review and finalize the themes.

Results

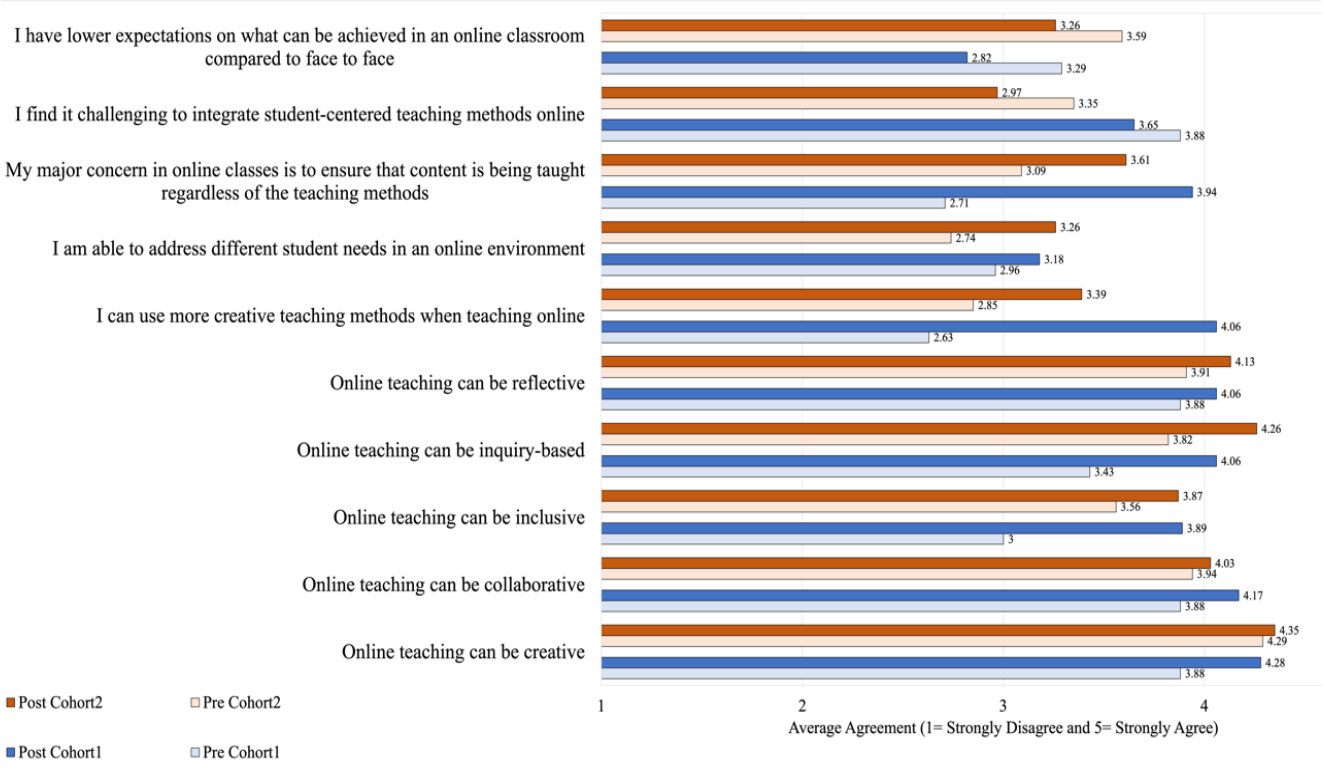
How TCs Perceive Online Teaching as a Teaching Modality

Figure 3 highlights the average responses of TCs' initial and final pedagogical views toward online teaching. Pre-survey findings indicate that TCs held relatively negative views of online teaching. Teacher candidates mostly neither agreed/disagreed or slightly agreed that online teaching can be reflective, inquiry-based, inclusive, collaborative, and creative. At the end of the course, the average agreement increased significantly on all indicators across both cohorts. For both cohorts, the statements that showed the greatest positive difference are: "Online teaching can be inquiry-based" (average increased from 3.43 to 4.06 in Cohort 1 and 3.82 to 4.26 in Cohort 2) and "inclusive" (average increased from 3 to 3.89 in Cohort 1 and 3.56 to 3.87 in Cohort 2). It is also worth noting that pre-survey pedagogical perceptions toward online teaching were consistently more positive in Cohort 2 compared to Cohort 1 on all five indicators. Moreover, the averages on post-survey responses on four indicators (creative, collaborative, inquiry-based, and reflective) were all above 4 indicating agreement. Only one indicator (inclusive) recorded 3.89 in Cohort 1 and 3.87 in Cohort 2 which is very close to the agree level.

Furthermore, TCs agreed that they can use creative teaching methods and ideas (average agreement increased in the post-survey compared the pre-survey from 2.63 to 4.06 in Cohort 1 and from 2.85 to 3.39 in Cohort 2). They also agreed that through differentiating instruction or other methods, they can address different student needs and academic abilities in an online environment (average agreement increased from 2.96 to 3.18 in Cohort 1 and from 2.74 to 3.26 in Cohort 2). Additionally, TCs' agreement decreased on statements related to i) finding it challenging to integrate student-centred and inquiry-based teaching methods in online teaching (such as group discussions, online activities and simulations, virtual labs, etc.), ii) lowering expectations on what can be achieved in an online classroom when compared to a face-to-face setting (in terms of curriculum coverage and teaching methods), and iii) assessing students' understanding online, especially certain skills such as higher order thinking, cooperative learning, or hands-on learning skills. Taken together, these findings indicate an improvement in what TCs perceive as achievable in online teaching.

Figure 3

Teacher Candidates' Initial and Final Pedagogical Perceptions of Online Teaching



However, despite improvement on being able to address different student needs online, the post-survey numbers are closer to 3 (neither agree or disagree), and thereby are not close to the agreement level in both cohorts. Similar results are observed on ability to use creative teaching methods online in Cohort 2. Additionally, TCs' agreement with the statement "My major concern in online classes is to ensure that the course content is being taught (achieving the curriculum objectives) regardless of the teaching methods" increased to reach 3.94 in Cohort 1 and 3.61 in Cohort 2 approaching an agreement level in both cohorts, hence not showing improvement upon comparing post- to pre-survey results.

Overall, TCs expressed an improvement in their pedagogical views of online teaching which entail how they describe online teaching. In the next section, findings related to TCs' perception of the impact of the online STEM course on their technological and pedagogical skills will be highlighted.

Impact of the Course on TCs' Technological and Pedagogical Skills for Online Teaching

Figure 4 highlights TCs' account of the effectiveness of the course on their TPACK across both cohorts. In the post-survey, TCs indicated that they found the course either helpful or very helpful in i) learning to use new software programs (76% in Cohort 1 and 90% in Cohort 2), ii) improving their use of familiar software programs (64% in Cohort 1 and 90% in Cohort 2), iii) organizing and presenting ideas online (65% in Cohort 1 and 84% in Cohort 2), iv) applying and utilizing technology in their teaching (70% in Cohort 1 and 87% in Cohort 2), v) learning methods to increase student engagement in online settings (70% in Cohort 1 and 84% in Cohort 2), and vi) learning methods to increase student

agency in online settings (59% in Cohort 1 and 74% in Cohort 2). Overall, it is evident that the course had a positive impact on the stated technological and pedagogical skills necessary for online teaching. This impact was consistent across both cohorts, while noting that Cohort 2 perceived the impact more positively compared to Cohort 1.

Figure 4

Teacher Candidates' Account of the Influence of the Course on Various Aspects of Their Technological and Pedagogical Skills

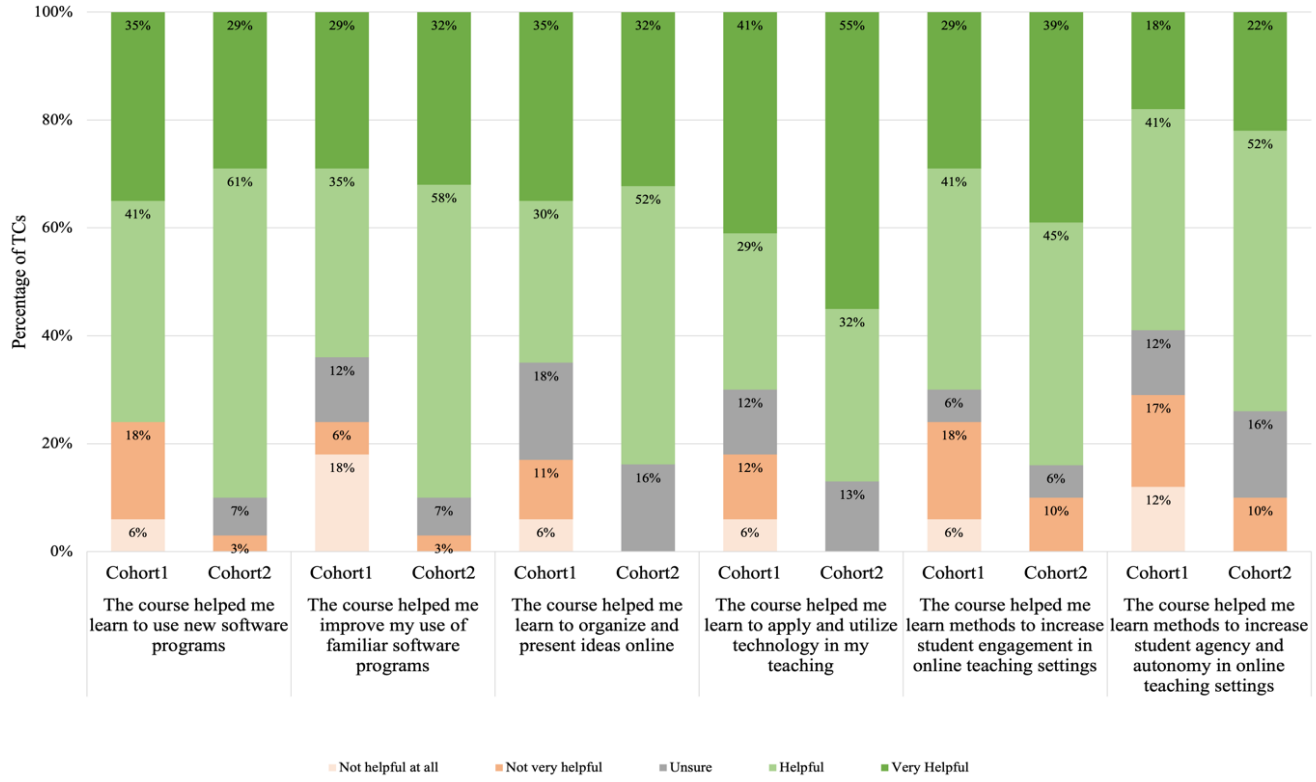


Table 1 details the course effectiveness in terms of enhancing TCs' online teaching and assessment strategies. Teacher candidates self-assessed their familiarity with and competence using various online pedagogical strategies. Comparing pre- to post-survey data, TCs' scores improved in both cohorts on almost all online teaching strategies: synchronous teaching (facilitating direct instruction with students), self-directed learning (sending resources and materials for students to study on their own), virtual labs, online simulations and digital games, online discussion or chat tools, content creation software such as Moviemaker (with exception of Cohort 1), and website creation. Similarly, TCs' scores improved on items related to online assessment strategies, such as online quizzes and tests (with exception of Cohort 1), lab or simulation reports, and content creation by students for assessment including videos, presentations, websites, and ePortfolios.

Table 1

Percentages of TCs Stating That They are Familiar with and Competent in Using Specific Teaching and Assessment Strategies Online

Strategies	Cohort 1		Cohort 2	
	Pre-survey (N=24)	Post-survey (N=18)	Pre-survey (N=34)	Post-survey (N=31)
Synchronous teaching	63%	89%	53%	87%
Self-directed learning	79%	83%	74%	77%
Virtual labs	33%	72%	15%	61%
Online simulations and digital games	46%	89%	47%	58%
Online discussion or chat tools	75%	89%	61%	71%
Content creation software	92%	89%	71%	84%
Website creation	21%	83%	12%	58%
Online quizzes and tests	83%	82%	71%	90%
Lab or simulation reports	29%	76%	29%	58%
Content creation by students for assessment	46%	71 %	47%	77%

Overall, the survey findings show a notable improvement in TCs' technological and pedagogical skills and abilities utilizing innovative teaching and assessment strategies in online teaching. Furthermore, to provide detailed insight on their survey responses, TCs responded to two open-ended questions in the post-survey. Since both cohorts showed similar trends in findings emanating from the quantitative survey responses, their open-ended responses were aggregated for the qualitative analysis. First, TCs elaborated on the extent to which they perceived the course successful in terms of modeling specific pedagogical and technological skills to use in online teaching. Common themes included: 1) learning specific skills needed for online teaching (16 out of 29 responses) and 2) learning about specific tools and resources (9 out of 29 responses).

In relation to the skills needed for online teaching, TCs mentioned communication and collaboration in online environments, choosing and using digital resources (course emphasis on online teaching pedagogies), comfort using new software, organization, and providing feedback to students. Teacher candidates reflected on pedagogy and how the course incorporated those skills in its content and assignments. They said:

> *I found this course very successful in teaching specific pedagogical and technological skills to use in online teaching. I've learned a number of new digital tools as well as pedagogical skills such as teaching through timelines, case studies and building an online website/digital resource for teaching. (TC1)*
>
> *Pedagogy was a huge focus and the instructor helped me integrate this with technological skills. This was effective both in-person and online. This was one of the only courses I've had that clearly discussed pedagogy and what it means to develop pedagogical skills to become more effective teachers. (TC2)*
>
> *This course was successful in teaching me what to look for, to be critical of technology (don't just use it to use it), and how to align curriculum to online tech. (TC4)*

They also reflected on the fact that the course was offered online with facilitated modeling:

> *This course is very well suited to online delivery because of the collaborative projects which do not require in-person meetings, discussion groups which are organized through Zoom, and using multimedia content for the projects. In fact, class time was used more effectively online than in-person, especially in the breakout rooms. The course models effective online instruction and has been very useful for me in changing my attitude towards online teaching while building skills. (TC6)*

With respect to using online tools and resources, TCs said:

> *I learned to create online resources, making digital video games, and websites for the science curriculum. These are essential skills to use for my future teaching practices. (TC8)*
>
> *We used a lot of different technologies in our assignments that increased my comfort level with them. I learned about other digital tools that could be used to enhance teaching and various pedagogical strategies that work online (like the case studies). (TC10)*

On the other hand, TCs also responded to an open-ended question about online teaching skills needing ongoing improvement or reinforcement despite the material offered in the course. Analysis of TCs' responses identified four themes: enhancing student engagement and collaboration in online environments (10 out of 31 responses), online assessment (7 out of 31), synchronous teaching skills especially classroom management (6 out of 31), and more practice needed to master tools especially in real-world classroom scenarios (6 out of 31). They said:

> *I think ongoing assessment and participation needs improvement because I feel like it's difficult to get students to participate in discussion and I feel ongoing assessment is difficult because I don't get to see the students. I also think taking care of student mental health needs improvement because you aren't seeing them in person every day, so it makes it more difficult to recognize behaviour changes and check in with students meaningfully. (TC5)*
>
> *I think just using them {the tools} practically with students and seeing what is effective with high school levels students would be beneficial. It's easy to talk about a resource being great but it actually being good in practice is different. (TC11)*

Discussion and Conclusion

In this paper, we explored TCs' perceptions of online teaching as a teaching modality and the impact of the STEM course on their technological and pedagogical skills necessary for online teaching. First, with respect to pedagogical perceptions of online teaching, TCs showed more positive perceptions at the end of the course about the potential of online teaching environments to be creative, inclusive, collaborative, and reflective. These indicators are of specific importance as they relate to inquiry-based learning, student engagement, and inclusivity in STEM education which were noted to be challenging in online environments as reported by teachers during ERT (DeCoito & Estaiteyeh, 2022a). Yet, a few areas are noted for future exploration and further improvement, such as TCs' ability to address student differences online and the fact that they still prioritized content delivery over teaching methods. These findings parallel those of Han et al. (2017) and Aslan and Zhu (2017) who highlight the importance of attending to TCs' self-efficacy and perceptions toward technology; further they maintain that involving TCs in technology-centred experiences is essential to develop these perceptions. It is also worth noting that the observed impact of the course was consistent across both cohorts, despite higher levels of improvement in Cohort 2 compared to Cohort 1. This result may be due to relatively more negative initial perceptions of Cohort 1 as they experienced a more abrupt shift to online teaching at the time of conducting this study (academic year 2020-2021, the first year of the pandemic). This finding is in contradiction with Han et al.'s (2017) study in which TCs' initial beliefs minimally impacted the final outcomes.

Second, the results across both cohorts show a notable improvement in TCs' technological and pedagogical skills, as well as personal abilities utilizing innovative teaching and assessment strategies in online teaching. Teacher candidates shared how various elements of the course positively impacted their technological skills, such as using new software programs, improving use of familiar software programs, and organizing and presenting ideas online. Additional course elements mentioned by TCs include pedagogical skills necessary for online teaching, such as applying and utilizing technology in their teaching, and learning methods to increase student engagement and agency in online teaching settings. These skills are examples of the four general competency areas that are essential for digitally supported teaching in all subjects, according to the DiKoLAN framework (Von Kotzebue et al., 2021). Furthermore, with respect to examples of the three science-specific competency areas of the DiKoLAN framework and the four technology-related dimensions of the TPACK framework (TPACK, TPK, TCK, TK) (Koehler et al., 2013), TCs in both cohorts recorded higher scores in the post-survey compared to the pre-survey on items related to their familiarity with and competence using various online pedagogical strategies. These strategies include synchronous teaching, virtual labs, online simulations and digital games, online discussion tools, website creation for digital science resources, lab or simulation reports, and assessing content creation. However, two skills were noted as areas of improvement – developing competence in content creation software and utilizing online quizzes and tests for assessment.

Additionally, TCs highlighted that the course was particularly helpful as it modeled online teaching, offered specific online pedagogical skills, and provided teaching resources needed for online teaching. These findings are in accordance with other studies emphasizing the importance of focusing on

pedagogical skills and content-specific training along with technological skills (Aslan & Zhu, 2017; Burns et al., 2020; Mishra & Koehler, 2006; Schubatzky et al., 2023), as well as the importance of involving TCs in designing digital STEM education resources (Burron & Pegg, 2021; Milner-Bolotin, 2019) – which was a large emphasis in this course. Some areas of improvement especially in promoting student engagement and collaboration in online environments, online assessments, online classroom management, and applying what they learned in real classrooms were still noted by TCs. These are also commonly reported challenges by teachers and TCs, as is evidenced in the literature (Ali & Nath, 2023; Alvi, 2023; Margaliot & Gorev, 2020).

In conclusion, these findings highlight the positive impact of the digitally enriched STEM curriculum and ICT training embedded in this course in order to develop and enhance TCs' technological and pedagogical skills and their perceptions of online teaching as a teaching modality. This research highlights the role of extended exposure to experiences that are designed to cultivate TCs' TPACK in teacher education, in which technological competencies are simultaneously refined along with pedagogical methodologies (Aslan & Zhu, 2017; Burns et al., 2020; Mishra & Koehler, 2006; Schubatzky et al., 2023). This conclusion confirms Karakaya's (2017) recommendation that improving TCs' technological knowledge should be part of science methods courses and not only educational technology courses, to ensure that TCs design lessons that integrate all TPACK components, as highlighted in this study.

Limitations and Implications

A major limitation in this study is reliance on self-reported assessment by TCs to reflect their development of pedagogical and technological skills. Although TCs' coursework was collected to analyze their skills in planning for online teaching, this analysis is beyond the scope of this paper as it will reflect their planning rather than facilitation of online classes. Future research can follow-up with TCs during their practicum or future classrooms to obtain a complete picture of their competence, challenges, and successes in online classes.

This research informs teacher educators and educational researchers, especially those in Canada, about the successes of teacher preparation programs and serves as a model for the development and implementation of high-quality online teaching training. This research provides insights for teachers, department leaders, policy makers, and teacher educators. Specifically, the research highlights the importance of providing adequate opportunities for TCs to cultivate and develop their TPACK framework, with a focus on STEM-contextualized technological and pedagogical skills, which seemed to be lacking during ERT. It aims to chart a path forward for developing essential skills and strategies that enable TCs and teachers to effectively engage in virtual classrooms, thereby ensuring rich, inclusive, and effective online learning experiences for all learners.

References

Ali, R., & Nath, S. (2023). Pre-service teachers' experiences of remote online learning: Reimagining teacher education post-pandemic. *Educational Research*, *65*(3), 337–356. https://doi.org/10.1080/00131881.2023.2223645

Alvi, E. (2023). Navigating online practice teaching (PT) amidst the COVID-19 pandemic: Exploring pre-service teachers' experiences in Pakistan. *Journal of Education for Teaching*, 1–19. https://doi.org/10.1080/02607476.2023.2241827

Aslan, A., & Zhu, C. (2017). Investigating variables predicting Turkish pre-service teachers' integration of ICT into teaching practices. *British Journal of Educational Technology*, *48*(2), 552–570. https://doi.org/10.1111/bjet.12437

Bahcivan, E., Gurer, M. D., Yavuzalp, N., & Akayoglu, S. (2019). Investigating the relations among pre-service teachers' teaching/learning beliefs and educational technology integration competencies: A structural equation modeling study. *Journal of Science Education and Technology*, *28*(5), 579–588. https://doi.org/10.1007/s10956-019-09788-6

Barbour, M. K. (2018). A history of K-12 distance, online, and blended learning worldwide. In K. Kennedy & R. E. Ferdig (Eds.), *Handbook of research on K-12 online and blended learning* (pp. 21–40). ETC Press.

Becker, S., Bruckermann, T., Finger, A., Huwer, J., Kremser, E., Meier, M., Thoms, L.-J., Thyssen, C., & von Kotzebue, L. (2020). DiKoLAN – Digital Competencies for Teaching in Science Education. Workgroup Digital Core Competencies. http://dikolan.de/

Bourgoin, R. (2023). Assessing the content knowledge, skills, and competencies of teacher candidates in an online learning environment. In P. Seitz & S. L. Hill, *Assessment of online learners* (1st ed., pp. 91–108). Routledge. https://doi.org/10.4324/9781003347972-7

Brinia, V., & Psoni, P. (2022). Online teaching practicum during COVID-19: The case of a teacher education program in Greece. *Journal of Applied Research in Higher Education*, *14*(2), 610–624. https://doi.org/10.1108/JARHE-07-2020-0223

Burns, A., Danyluk, P., Kapoyannis, T., & Kendrick, A. (2020). Leading the pandemic practicum: One teacher education response to the COVID-19 crisis. *International Journal of E-Learning & Distance Education*, *35*(2), 1–25. https://www.ijede.ca/index.php/jde/article/view/1173

Burron, G., & Pegg, J. (2021). Elementary pre-service teachers' search, evaluation, and selection of online science education resources. *Journal of Science Education and Technology*, *30*(4), 471–483. https://doi.org/10.1007/s10956-020-09891-z

Carrillo, C., & Flores, M. A. (2020). COVID-19 and teacher education: A literature review of online teaching and learning practices. *European Journal of Teacher Education*, *43*(4), 466–487. https://doi.org/10.1080/02619768.2020.1821184

Coskun Karabulut, H., Elcan Kaynak, N., & Kariper, I. A. (2023). Pre service teachers' engagement with STEM-based hands-on activities in online chemistry laboratory courses. *Research in Science & Technological Education*, 1–21. https://doi.org/10.1080/02635143.2023.2215170

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications, Inc.

DeCoito, I. (2023). STEMifying teacher education – a Canadian context. In A. M. Al-Balushi, L. Martin-Hansen, & Y. Song (Eds.), *Reforming science teacher education programs in the STEM era: International practices* (pp. 35–52). Springer.

DeCoito, I., & Estaiteyeh, M. (2022a). Online teaching during the COVID-19 pandemic: Exploring science/STEM teachers' curriculum and assessment practices in Canada. *Disciplinary and Interdisciplinary Science Education Research*, *4*(1), 8. https://doi.org/10.1186/s43031-022-00048-z

DeCoito, I., & Estaiteyeh, M. (2022b). Transitioning to online teaching during the COVID-19 pandemic: An exploration of STEM teachers' views, successes, and challenges. *Journal of Science Education and Technology*, *31*(3), 340–356. https://doi.org/10.1007/s10956-022-09958-z

DeCoito, I., & Vacca, S. (2020). The case for digital timelines in teaching and teacher education. *International Journal of E-Learning & Distance Education*, *35*(1), 1–36. https://www.ijede.ca/index.php/jde/article/view/1171

Dilling, F., & Vogler, A. (2023). Pre-service teachers' reflections on attitudes towards teaching and learning mathematics with online platforms at school: A case study in the context of a university online training. *Technology, Knowledge and Learning*, *28*(3), 1401–1424. https://doi.org/10.1007/s10758-022-09602-0

Gall, J. P., Gall, M. D., & Borg, W. R. (2005). *Applying educational research: A practical guide* (5th ed.). Pearson/Allyn & Bacon.

Han, I., Shin, W. S., & Ko, Y. (2017). The effect of student teaching experience and teacher beliefs on pre-service teachers' self-efficacy and intention to use technology in teaching. *Teachers and Teaching*, *23*(7), 829–842. https://doi.org/10.1080/13540602.2017.1322057

Henne, A., Möhrke, P., Thoms, L.-J., & Huwer, J. (2022). Implementing digital competencies in university science education seminars following the DiKoLAN framework. *Education Sciences*, *12*(5), 356. https://doi.org/10.3390/educsci12050356

Hodges, C. B., Moore, S., Lockee, B. B., Trust, T., & Bond, M. A. (2020). The difference between emergency remote teaching and online learning. *Educase Review*, *27*. https://er.educause.edu/articles/2020/3/the-difference-between-emergency-remote-teaching-and-online-learning

Hofer, M., & Grandgenett, N. (2012). TPACK development in teacher education: A longitudinal study of preservice teachers in a secondary M.A.Ed. program. *Journal of Research on Technology in Education*, *45*(1), 83–106. https://doi.org/10.1080/15391523.2012.10782598

Hojeij, Z., & Baroudi, S. (2021). Engaging pre-service teachers in virtual field experience during COVID-19: Designing a framework to inform the practice. *International Journal of Distance Education Technologies*, *19*(3), 14–32. https://doi.org/10.4018/IJDET.2021070102

Johnson, N. (2023). *2023 pan-Canadian report on digital learning trends in Canadian post-secondary education*. Canadian Digital Learning Research Association. http://www.cdlra-acrfl.ca/wp-content/uploads/2023/12/2023-Pan-Canadian-Report-EN.pdf

Joshi, S. (2023). TPACK and teachers' self-efficacy: A systematic review. *Canadian Journal of Learning and Technology*, *49*(2), 1–23. https://doi.org/10.21432/cjlt28280

Kang, H. J., Farber, M., & Mahovsky, K. A. (2021). Teachers' self-reported pedagogical changes: Are we preparing teachers for online STEM education? *Journal of Higher Education Theory and Practice*, *21*(10). https://doi.org/10.33423/jhetp.v21i10.4640

Karakaya, O. (2017). *Investigating preservice teachers' TPACK integration into lesson planning* [Doctoral dissertation, Iowa State University]. https://dr.lib.iastate.edu/handle/20.500.12876/31411

Koehler, M. J., Mishra, P., & Cain, W. (2013). What is technological pedagogical content knowledge (TPACK)? *Journal of Education*, *193*(3), 13–19. https://doi.org/10.1177/002205741319300303

Krug, M., Thoms, L.-J., & Huwer, J. (2023). Augmented reality in the science classroom—Implementing pre-service teacher training in the competency area of simulation and modeling according to the DiKoLAN framework. *Education Sciences*, *13*(10), 1016. https://doi.org/10.3390/educsci13101016

Long, C. S., Sinclair, B. B., Fraser, B. J., Larson, T. R., & Harrell, P. E. (2022). Preservice teachers' perceptions of learning environments before and after pandemic-related course disruption. *Learning Environments Research*, *25*(2), 343–357. https://doi.org/10.1007/s10984-021-09376-9

Margaliot, A., & Gorev, D. (2020). Once they've experienced it, will pre-service teachers be willing to apply online collaborative learning? *Computers in the Schools*, *37*(4), 217–233. https://doi.org/10.1080/07380569.2020.1834821

Milner-Bolotin, M. (2019). Technology as a catalyst for twenty-first-century STEM teacher education. In S. Yu, H. Niemi, & J. Mason (Eds.), *Shaping future schools with digital technology: An international handbook* (pp. 179–199). Springer. https://doi.org/10.1007/978-981-13-9439-3_11

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record: The Voice of Scholarship in Education*, *108*(6), 1017–1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Müller, L., Thoms, L., Möhrke, P., Henne, A., & Huwer, J. (2022). Testing new concepts in university teacher training for the acquisition of digital competencies according to DiKoLAN – development and investigation of the effectiveness of a teaching-learning module in the field of simulation and modelling. *CHEMKON*, *29*(S1), 349–354. https://doi.org/10.1002/ckon.202200022

Raby, C., Tremblay-Wragg, É., Viola, S., & Meunier, H. (2020). Portfolio numérique en contexte de pandémie. Perception des futurs enseignants à l'égard du portfolio numérique en formation initiale: Propositions pour l'évaluation formative des compétences professionnelles en contexte de pandémie et d'enseignement à distance. *Revue Internationale Des Technologies En Pédagogie Universitaire*, *17*(3), 209–222. https://doi.org/10.18162/ritpu-2020-v17n3-19

Schreier, M. (2013). Qualitative content analysis. In U. Flick (Ed.), *The SAGE handbook of qualitative data analysis*. SAGE.

Schubatzky, T., Burde, J.-P., Große-Heilmann, R., Haagen-Schützenhöfer, C., Riese, J., & Weiler, D. (2023). Predicting the development of digital media PCK/TPACK: The role of PCK, motivation to use digital media, interest in and previous experience with digital media. *Computers & Education*, *206*, 104900. https://doi.org/10.1016/j.compedu.2023.104900

Shulman, L. (1987). Knowledge and Teaching: Foundations of the New Reform. *Harvard Educational Review*, *57*(1), 1–23. https://doi.org/10.17763/haer.57.1.j463w79r56455411

Tembrevilla, G., & Milner-Bolotin, M. (2019). Engaging physics teacher-candidates in the production of science demonstration videos. *Physics Education*, *54*(2), 025008. https://doi.org/10.1088/1361-6552/aaf95d

Tondeur, J., Scherer, R., Siddiq, F., & Baran, E. (2020). Enhancing pre-service teachers' technological pedagogical content knowledge (TPACK): A mixed-method study. *Educational Technology Research and Development*, *68*(1), 319–343. https://doi.org/10.1007/s11423-019-09692-1

Van Nuland, S., Mandzuk, D., Tucker Petrick, K., & Cooper, T. (2020). COVID-19 and its effects on teacher education in Ontario: A complex adaptive systems perspective. *Journal of Education for Teaching*, *46*(4), 442–451. https://doi.org/10.1080/02607476.2020.1803050

Von Kotzebue, L. (2022). Beliefs, self-reported or performance-assessed TPACK: What can predict the quality of technology-enhanced biology lesson plans? *Journal of Science Education and Technology*, *31*(5), 570–582. https://doi.org/10.1007/s10956-022-09974-z

Von Kotzebue, L., Meier, M., Finger, A., Kremser, E., Huwer, J., Thoms, L.-J., Becker, S., Bruckermann, T., & Thyssen, C. (2021). The framework DiKoLAN (digital competencies for teaching in science education) as basis for the self-assessment tool DiKoLAN-grid. *Education Sciences*, *11*(12), 775. https://doi.org/10.3390/educsci11120775

Yin, R. K. (2014). *Case study research: Design and methods* (5th ed.). SAGE.

Authors

Mohammed Estaiteyeh is an Assistant Professor of Digital Pedagogies and Technology Literacies in the Faculty of Education at Brock University, Canada. He is the subject team leader for digital technology courses in the Teacher Education program. Dr. Estaiteyeh's research focuses on educational technologies; teacher education; STEM education; and differentiated instruction.
Email: mestaiteyeh@brocku.ca

Isha DeCoito is an Associate Professor and a Faculty Scholar in the Faculty of Education, with a cross-appointment to the Faculty of Science at Western University, Canada. Her research focuses on equity, diversity, inclusion, and decolonization in STEM education; digital technologies; mentoring and professional development; and environmental education. *Email*: idecoito@uwo.ca

Mariam Takkouch is a PhD candidate in Curriculum Studies at the Faculty of Education, Western University in Canada, with a collaborative specialisation in environment and sustainability. Her research focuses on science and environmental education, climate change education, social justice, outdoor education, and experiential learning in K-12 and postsecondary programs. *Email*: mtakkou@uwo.ca