

Elementary STEM Teachers' Open Educational Resources and TPACK in a Professional Learning Network: A Case Study

Yujin Park

Georgia Southern University, USA

Jewoong Moon

University of Alabama, USA

Hunhui Na

Florida State University, USA

Abstract

Research attention to investigating elementary STEM teachers' Professional Learning Networks (PLNs) has grown. However, what types of Open Educational Resources (OER) and Technological, Pedagogical, and Content Knowledge (TPACK) elementary STEM teachers share in their PLNs are still under-examined. This case study aims to explore elementary STEM teachers' use of OER, types of TPACK, and their relationships. Using qualitative content analysis, we analyzed qualitative messages extracted from a Facebook community for elementary STEM teachers. The results showed that tools and tips were the most commonly shared among the various OER types, and technology-related knowledge (i.e., TK and TPK) emerged dominant within the PLN. Also, we discuss the implications of elementary STEM teachers' discourses on OER and TPACK in a PLN.

Keywords: Elementary STEM teachers, open educational resources, TPACK, professional learning networks

Park, Y., Moon, J. & Na, H. (2025). Elementary STEM teachers' open educational resources and TPACK in a professional learning network: A case study. *Online Learning*, 29(1), 192–213. DOI: <https://doi.org/10.24059/olj.v29i1.4102>

Professional Learning Networks (PLNs) offer teachers opportunities to interact with other educators beyond their local contexts, fostering accessibility and flexibility for engagement. Studies have reported that PLNs' connective, self-regulated, and collaborative natures can improve social and cognitive developmental capabilities (Trust et al., 2016). Furthermore, PLNs enable teachers to identify student characteristics and obtain effective digital tools with suitable teaching methods (Nochumson, 2019).

In STEM education, developing interdisciplinary and cross-curricular learning tasks is demanding, necessitating extra support and resources for elementary STEM teachers (Teo & Ke, 2014). In particular, integrating creative ideas and technology into teaching practices is essential in STEM education to provide authentic learning experiences for students. In this sense, Open Educational Resources (OER) shared in PLNs are advantageous for elementary STEM teachers due to their design flexibility, cost efficiency, and accessibility (Bencheva, 2020). Given that adopting OER for STEM courses requires teachers to use knowledge regarding technology, pedagogy, and content, the TPACK framework can help researchers understand what aspects of OER elementary STEM teachers would investigate or need for their practices.

Research has largely explored how the intersections of the TPACK framework (Mishra & Koehler, 2006) emerge from teachers' PLNs (van Bommel et al., 2020). A study examining math teachers' TPACK in PLNs reported that study participants mainly shared pedagogical content knowledge (PCK) involving “questions” and “offers” (Liljekvist et al., 2021). Furthermore, participating in PLNs has been associated with enhancing STEM-related content knowledge, pedagogical competence, digital literacy, and self-efficacy (Pelton, 2018).

Although the importance of STEM teachers' TPACK and PLNs is on the rise, few studies have provided an in-depth investigation of the specific OER that emerge in relation to TPACK among elementary STEM teachers in PLNs. Moreover, existing PLN studies have focused on K-12 teachers' general experiences in PLNs but appeared limited in illustrating how the dynamics of OER and PLN discourses emerge. Accordingly, this case study aims to investigate OER and TPACK in a PLN for elementary STEM teachers. The results of this study can provide a deeper understanding of elementary STEM teachers' OER use and knowledge related to educational practices and can also contribute to discussions about the future of OER by providing a broader picture of OER use in STEM education.

The research questions guiding this study are:

- RQ1. What are the dominant Open Educational Resources (OER) types in a Professional Learning Network (PLN) for elementary STEM teachers?
- RQ2. What types of TPACK do elementary STEM teachers mainly discuss in a PLN?
- RQ3. What are the relationships between the types of OER and TPACK in an elementary STEM teachers' PLN?

Literature Review

Teacher Professional Learning Networks

A PLN is a global group or network developed from self-selected connections and collaborators with shared interests (Davis, 2013). PLNs support teachers' ongoing learning in unique networks, and digital technologies (e.g., social media) can mediate their engagements with people, spaces, and tools regardless of time or location issues (Krutka et al., 2017).

PLNs are often compared with Community of Practices (CoP) because they share common characteristics, such as interactions with network components, sharing information, or receiving emotional support. These terms are often used interchangeably because members of both CoPs and PLNs routinely engage in discussions, interact with one another, and voluntarily exchange information. Whereas PLNs are informal networks that characterize individualized learning for personal and professional development (Krutka et al., 2017), CoPs are a foundational concept of a broader social learning system with group members who organize group norms, build relationships, decide the main focus and goals of the group, and share resources (Hass et al., 2020; Lave & Wenger, 1991).

PLNs are informal and collaborative networks that enable the exchange of resources, knowledge, and ideas via interpersonal connections. Empirical studies have investigated how teachers behave in their PLNs and why they engage in PLNs. Trust (2017) identified that in-service teachers actively evaluate, collect, and organize shared knowledge using digital tools, such as Pinterest, Symbaloo, Edmodo, or email. Moreover, Oddone's (2022) qualitative case study showed five selected teachers' use of PLNs in their professional learning. The participants' identities and the nature of their professional learning in PLNs were individual, social, and digitally connected.

These PLN environments offer unique opportunities for STEM teachers to enhance their instructional practices without the constraints of traditional on-site professional development programs (National Research Council, 2009; Pepler, 2017). However, as a subset of the broader field of STEM education, informal professional development for STEM teachers has received less attention, particularly regarding how teachers develop their professional competencies in these settings. Despite this limitation, studies indicate that informal professional learning in PLNs contributes to teacher professional growth by showing improvement in teachers' STEM literacy (Jackson & Mohr-Schroeder, 2018), encouraging experimentation with innovative pedagogical approaches, and fostering the development of crucial skills such as creativity, social interaction, and leadership, all of which are directly applicable to classroom teaching (Terrazas-Marín, 2018).

In particular, elementary STEM teachers need to develop a variety of knowledge and skills to plan and deliver STEM learning activities. Compared to other subject disciplines, STEM education is unique by its nature because the content in STEM is rapidly and consistently evolving, and STEM education generally focuses on student-centered scientific inquiry that encourages the use of new tools or equipment (Lesseig et al., 2016; Polgampala et al., 2017). In addition to developing STEM content knowledge, STEM teachers must understand pedagogical knowledge and skills for integrative and cross-disciplinary approaches emphasized in STEM

education (Margot et al., 2019). These professional learning needs of elementary STEM teachers, however, are less likely to be addressed by their teacher preparation programs because many elementary STEM teachers have been trained within a single subject discipline (e.g., mathematics or biology) during their teacher preparation program (Aslam et al., 2018; Geng et al., 2019).

For many elementary STEM teachers, PLNs provide opportunities to meet their diverse professional learning needs. Teachers can find needed content or pedagogical knowledge as well as teaching resources through their PLNs (Beach, 2018; Trust et al., 2016). In addition, they can also find helpful advice or managerial strategies to properly plan and coordinate STEM activities that are frequently involved with financial and organizational issues (Aslam et al., 2018). With the development of information technology (e.g., the internet), many elementary STEM teachers now use digital tools (e.g., Facebook and Twitter/X) to build their own PLNs and leverage the affordances beyond their local contexts (Carpenter & Krutka, 2016). Irrespective of the context of PLNs—face-to-face, online, or blended—PLNs can offer professional learning opportunities for elementary STEM teachers in myriad ways.

Open Educational Resources (OER)

Open Educational Resources (OER) refer to works that are useful for educational purposes and are available to the public for free. These resources are not subject to copyright restrictions and rather allow users to manage the resources perpetually. OER include instructional materials, modules, text, videos, assessments, and any formats used to support educational activities (Hewlett Foundation, 2015).

OER provides a significant benefit to teachers and students by offering access to high-quality educational materials at no cost. The spectrum of OER encompasses a wide range of educational materials, including comprehensive courses, individual course components, specific modules, discrete learning objects, and open-access textbooks. Additionally, OER may take the form of openly licensed video content (often available via streaming), assessment tools, software applications, and various other resources or methodologies designed to facilitate students' knowledge acquisition. This diverse array of OER formats reflects the multifaceted nature of educational resources in the digital age and offers educators and learners a rich variety of tools and materials to support their teaching practices (Butcher & Moore, 2015) which allow students to visualize abstract science concepts and make complex STEM topics more accessible. As another example, Code.org provides users with free coding courses and projects that are essential for developing computational thinking skills integral to many STEM fields. These OER types expand users' opportunities to leverage their teaching and learning by providing access to up-to-date, interactive, and engaging materials that might otherwise be unavailable due to cost or resource constraints. Research reports that teachers have typically utilized OER to leverage the quality of their teaching, such as instructional strategy selection and application. Instructional strategies are one type of OER providing informal tips to guide specific and iterative instructional design (Jonassen, 1991). Aligned with a PLN, suggestions or sharing experiences of instructional strategy selection, application, and customization shared in the public domain meet the requirement of OER (Pawlowski & Bick, 2012).

OER have become increasingly significant for STEM teachers because its components provide accessible materials for classroom management and instructional lesson design. Online textbooks, instructional videos, websites, and quizzes were identified as OER materials used by STEM teachers for pedagogical purposes (Yassin & Jung, 2021). In particular, OER shared and reviewed by a PLN can fulfil STEM teachers' current needs in learning resources: (1) access to high-quality materials and (2) quality assurance of educational resources (Almendro & Silveira, 2018; Kimmons, 2015; Tang et al., 2020). Validation of educational resources is crucial because teachers need materials that can be easily applied in their classrooms. Additionally, a major challenge of using OER is to ensure the reliability and validity of public resources and their alignment with subject domain standards. Specifically, to promote the active use of OER, peer evaluation is critical. Informal learning that happens in a PLN is advantageous to facilitate the validation, distribution, and reproduction of OER aligned with their quality assurance.

PLN-supported informal learning among STEM teachers could synergistically contribute to the quality assurance of OER. Beaven (2018) reported on the lifecycle of OER used by teachers and showed that OER materials are typically evaluated by teachers and their colleagues and then adapted for delivery to students. Beaven (2018) also reinforced the idea that a PLN among teachers could play a role in mediating the uses of OER. In addition, Tang et al. (2020) demonstrated that teachers' perceived usefulness of OER significantly predicted their attitude toward OER. The study findings demonstrated the importance of promoting teachers' consolidation in selecting, using, and revising OER tailored to their instructional/learning contexts.

Despite the growing use of OER by STEM teachers, a significant gap exists in our understanding of how elementary STEM teachers specifically utilize OER within PLNs. While previous studies have examined OER use in general K-12 settings, there is limited research on the intersection of OER, TPACK, and PLNs in the context of elementary STEM education. A thorough analysis of how OER can promote certain areas of STEM teacher competency is thus essential. Therefore, in-depth research is indicated to better understand the role of PLNs in promoting the use, selection, and revision of OER tailored to the instructional/learning contexts of elementary STEM teachers and knowledge domains related to instructional practices.

Technological Pedagogical and Content Knowledge (TPACK)

The concept of TPACK has been evolving since Shulman's (1986) clarification of pedagogical content knowledge, which defines what teachers should know and be able to do in their teaching professions (Mishra & Koehler, 2006). The TPACK framework that has emerged combines the knowledge relevant to instruction with digital technologies (Niess, 2005) with the pedagogical and content knowledge. TPACK is viewed as the synergy between technology, pedagogy, and content knowledge, and it can be useful for both educational practitioners and researchers since they can apply it to develop teacher education programs and professional learning or to investigate the current status of teachers' knowledge and support (Harris, 2008).

In teachers' PLNs, the components of TPACK are varied. van Bommel et al. (2020) found that discussions in Swedish teachers' Facebook groups focused primarily on pedagogical and content knowledge (PCK) and learner understanding. Meanwhile, math teachers in six PLNs

mainly shared pedagogical content knowledge (PCK) by questioning and offering resources (Liljekvist et al., 2021). On the other hand, Parsons et al. (2019) found that the US teachers' PLNs focused on Technological Content Knowledge (TCK). Learning digital tools and new teaching methods or ideas were also the main characteristics of teachers' PLNs (Nochumson, 2019).

Regarding STEM teachers' TPACK competencies in professional development situations, Chai (2019) reviewed 20 articles about STEM teachers' professional development studies by using the TPACK framework. The primary finding showed that pedagogical knowledge (PK) was mainly provided via workshops, and reviewed studies exploring STEM teachers' professional development emphasized the use of technology to deliver a subject matter. Similarly, a recent literature review study (Huang et al., 2022) about STEM teachers' TPD programs found that most teacher professional development programs were focused on pedagogical knowledge (PK) and pedagogical content knowledge (PCK), whereas a few numbers of programs addressed technological content knowledge (TCK) and technological pedagogical content knowledge (TPACK) for elementary teachers.

Although the varied components of TPACK and types of OER for STEM teachers are demonstrated in PLNs, there is still a lack of exploration on how elementary STEM teachers enact shared resources and knowledge domains in these networks. Moreover, studies on teachers' TPACK mainly employed self-report, interviews, and performance assessments (Monjelat & Lantz-Andersson, 2020), while studies using data sources collected from real-life practice are needed to reflect the nature of TPACK (Rosenberg & Koehler, 2015). Therefore, analyzing the qualitative messages of a PLN could shed light on how teachers execute OER, TPACK, and their relationships in their practices.

Method

This study employed a case study as a research method (Yin, 2018). A case study design allows an in-depth exploration of the phenomenon of the case and its findings. Further, it helps researchers focus on research questions and implications by applying a detailed analysis of the case. A case study design appeared suitable for this study because we sought to explore a specific phenomenon about elementary STEM teachers' professional learning network on social media (i.e., Facebook), which is an authentic informal learning space where teachers seek and share educational resources and ideas.

The Case

For this case study, we chose a private Facebook group for elementary STEM teachers. This Facebook group was established in 2019 by a STEM teacher who is a K-5 STEM specialist in North Carolina (See Figure 1). As of March 2023, this Facebook group has approximately 50,000 members. Only members of this group can participate in the discussion and access the resources shared within the group. To become a member, individuals must provide detailed information (e.g., their school's location and years of experience in teaching elementary school-level STEM) and get approval from moderators of this group. Based on a brief informal survey that the group administrator posted, participants consisted of elementary STEM teachers from around the world. According to the results of the survey, 40% of the respondents were K-5

STEM or Makerspace teachers and 15% of the respondents were defined as K-5 classroom teachers. On average, over 15 new posts are uploaded daily in this group.

This group was chosen for several reasons. First, social media platforms, particularly Facebook groups, have emerged as significant spaces for teacher professional development and informal learning, offering unique insights into how educators share knowledge in the digital age (Carpenter & Krutka, 2015). Second, while research on online teacher communities is growing, there remains a notable gap in understanding how elementary STEM teachers specifically leverage these platforms for their professional growth and classroom practice (Trust et al., 2016). The group for elementary STEM teachers represented a rich case study opportunity due to its size, active engagement, and focused content area, allowing for an in-depth exploration of how STEM education resources and ideas are shared and implemented at the elementary level (Macià & García, 2016). Additionally, studying this group provided a window into the challenges and opportunities of STEM integration in elementary education.

The study was reviewed and approved by the Institutional Review Board (IRB) and deemed eligible for exemption of review after obtaining consent from the moderator of the group. Permission was achieved by guaranteeing the collection of only anonymized qualitative data. Additionally, as part of our agreement with the group moderator, researchers were required to share findings after publication with the community members. All data sources were stored only on the lead researcher's personal computer.

Data Collection and Analysis

Data sources for this study consisted of messages extracted from the Facebook group for elementary STEM teachers, including texts, URLs for videos or web pages, and images that teachers shared for one month between October and November 2021. We employed a multiple-methods study using both qualitative and quantitative data analysis approaches.

We used qualitative content analysis (Assarroudi et al., 2018) to explore distributions of OER and TPACK and descriptive and network analysis for OER and TPACK patterns and their relationships. Content analysis was suitable for this study because it helps analyze recorded communication messages (Cole, 1988), such as discussions on social media. In particular, we conducted inductive content analysis because few studies have discussed elementary STEM teachers' OER in PLNs, leading to only limited knowledge (Vears & Gillam, 2022).

Following the data analysis steps suggested by Vears and Gillam (2022), we first piloted the coding process before we extracted the main data sources to become familiar with the data, simulate the coding process, and determine initial codes. We used 582 messages in the pilot phases using integrated OER types and definitions of TPACK and instructional strategies. All researchers are saturated with the meaning of the codes for cohesive results. In the relevance check phase, we focused on the message itself and whether messages contained real resources for STEM teaching or not. The researchers coded the same dataset, and the final codes were determined by discussing the differences in understanding the codes. Through the pilot data analysis, Five OER types—course materials, instructional strategies, lesson plans, professional

development, and tools and tips—were selected with operationalized definitions based on the extracted data sources to contextualize the results (Butcher & Moore, 2015; Hewlett Foundation, 2015; Pawlowski & Bick, 2012; Yassin & Jung, 2021) (See Table 1). Regarding the definitions of instructional strategies and TPACK, we followed the definitions suggested by Jonassen (1991) and Koehler and Mishra (2013). (See 2 and 3)

Figure 1

The Facebook Group for Elementary STEM Teachers

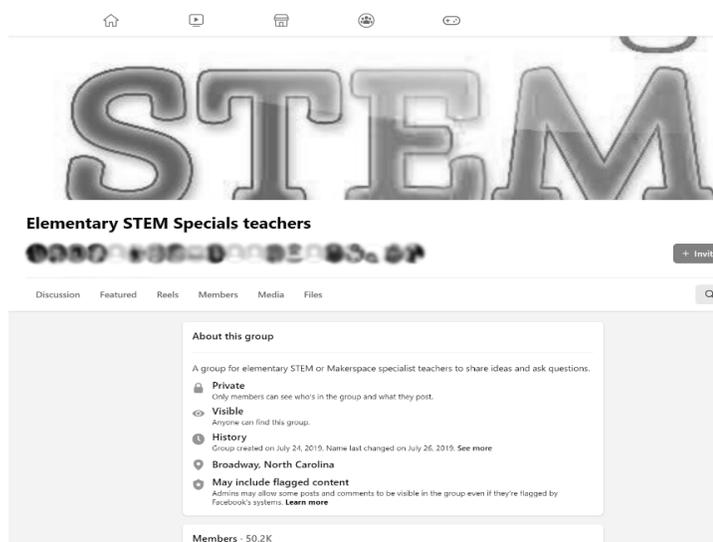


Table 1

Definitions of OER Types

Types	Definition	Examples
Course Material (CM)	General materials to be applied to classroom instruction (e.g., videos, images, resources for hands-on activities, worksheets, templates, etc.)	Here are my top 3 favorites: https://edgeucating.com/.../global-futures-creating.../ https://edgeucating.com/.../kais-clan-interactive.../ And of Dash is a must!

Instructional Strategy (IS)	Intellectual resources verbally described related to STEM instruction based on experiences (e.g., Sequence of lessons, manual for device uses, etc.)	Students program the robots to create polygons using a rug as the four quadrants. They program the robot to drop chips at the coordinates and they program the robots to state the coordinates.
Lesson Plan (LP)	Lesson plans that can be used in the instruction	The best way I've found to organise my kids/standards/ my planning is to divide our quarters into a school wide emphasis. Q1- scientific skills with EDP challenges, Q2 - coding and computer science...
Professional Development (PD)	Resources for teacher learning or activities	STEM MINDS has launched Professional Development Micro-credentials, for teachers, backed by Digital Promise. STEM MINDS is on a mission to empower our teachers with tools and skill building opportunities so they can continue to thrive supporting our children.
Tools and Tips (T&T)	Information about open source (e.g., code.org), topics for special events (Halloween, Christmas, vacation, etc.), or activity photos and descriptions	Well, aside from Bill Nye and Magic School Bus, I would agree with the Baking Impossible, Making Fun. I would love to show Apollo 13 if it were appropriate.

The main data analysis included the relevance check, coding, and analysis of the distributions of types of OER, instructional strategies, and TPACK, and relationships between OER and TPACK. A total of 1,770 messages were extracted as the initial raw data. After discussing the different decisions of coding for types of OER, instructional strategies, and TPACK, 1,346 messages were coded for types of OER, 212 messages for instructional strategies, and 1,596 messages were included in TPACK as the final data for coding processes. The 1,329 messages coded for both OER and TPACK were applied for the network analysis to identify the relationships between OER and TPACK. The messages were analyzed by applying multiple codes since some messages implied more than two types of OER and TPACK in one message. We used Microsoft Excel and Gephi (<https://gephi.org>) for data analysis and visualization. Gephi is an open-source software for network visualization and analysis, revealing patterns and trends from data (Bastian et al., 2009).

Table 2

Examples of Instructional Strategies

	Examples
Contextualizing instruction (CI)	I give a group discussion at the beginning asking them what they think our challenges may be with this STEM and what design solutions they could consider. It helps immensely.

Present and cue lesson content (PC)	I like to give examples of assembly techniques but I never show a final project. If I do, they just duplicate it.
Activating learner processing of instruction (AP)	After the guessing contest we calculated out how many cases that would be in a year. (Oops, 93!) You could always make a large graph paper and have them fill in coordinates in a certain color Post It notes to make a pixelated picture too.
Assess learning (AL)	I use Quizizz and make quick exit tickets that are self grading. You can ask questions about vocabulary.
Sequencing instructional events (SE)	I have them for 45 minutes. First, I displayed two different pictures of the book covers... Ask for those that had never heard the story...

Table 3*Definitions of TPACK*

	Definition	Examples
Content Knowledge (CK)	Knowledge of the subject matter to be taught (e.g., knowledge of facts and concepts of subjects)	FREE Multiplying Decimals Using Models - Printable PDF file. Model the product of two decimals by finding the area of a rectangle. Free template to print, cut out and laminate.
Pedagogical Knowledge (PK)	Knowledge of teaching and learning (e.g., learning activities, theories, processes, or practices)	You can do the activities without the reading but read through the units! You can pick and choose what you do. I have found the kids need multiple days for projects so get some good storage figured out.
Technology Knowledge (TK)	Knowledge of the standard or emerging technologies, including online learning platforms, websites, or skills to manipulate tools	The time to create the design isn't the problem- it's the time it takes to print. I would imagine that cup (if it is life sized) would take at least 15 hours to print.
Pedagogical Content Knowledge (PCK)	Knowledge of both content and pedagogy, including applying appropriate pedagogical approaches for a specific content	Space is a subject I've found kids will ask endless questions and will listen to answers for long periods of time. I once had to cut off a 20 min Q+A with first graders all listening intently the whole time.
Technological Content Knowledge (TCK)	The knowledge that concerns representations using technology to deliver specific topics	Science Max for both age groups. The concepts are hard enough for older kids, but the visuals are great for younger kids.
Technological Pedagogical Knowledge (TPK)	Knowledge of using emerging technologies to support general teaching and learning activities	I came up with all kinds of 'holes' using poster board strips, tubes, etc. and I used foamcore to create the greens (a basic rectangle with 3/4' walls to create a low box). Made some examples then...

Technological Pedagogical Content Knowledge (TPACK)	Knowledge of using emerging technologies to represent the subject with pedagogical activities	We were teaching how turtles return to the same beach using magnetic input. We laser cut beaches on card board and inserted an unfolded paper clip into it...
---	--	--

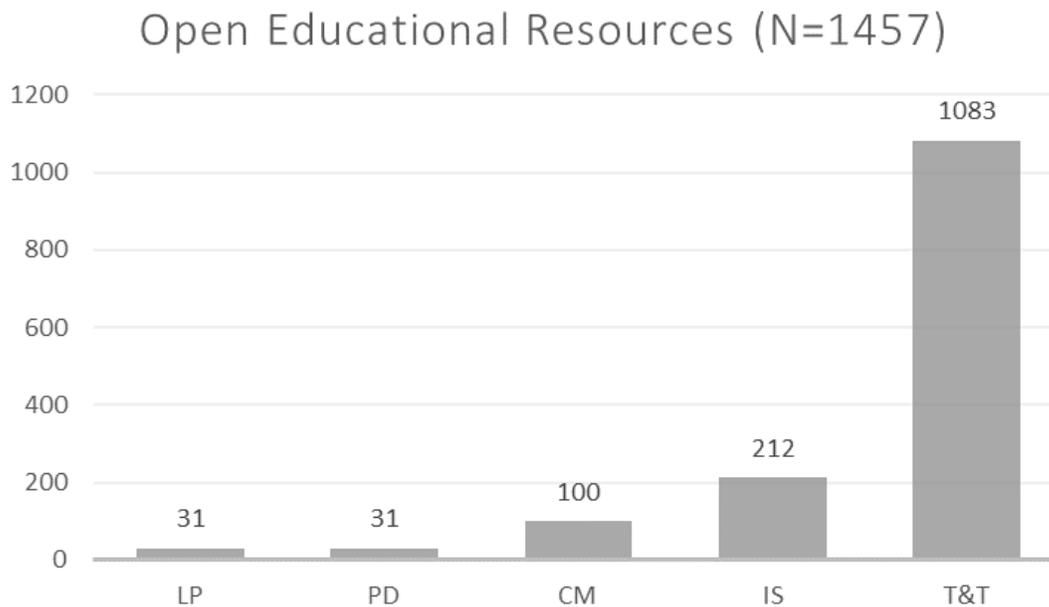
Findings

RQ1. What Are the Dominant Open Educational Resources (OER) Types in a Professional Learning Network (PLN) for Elementary STEM Teachers?

Across five OER types (i.e., lesson plans, professional development, course materials, instructional strategies, and tools and tips), the most prevalent OER type was tools and tips (N=1083, 74.3%), followed by instructional strategies (N=212, 14.6%). On the other hand, lesson plans and professional development for teachers (N= 31, 2.1%) were the least-shared type among elementary STEM teachers in the PLN. (See Figure 2)

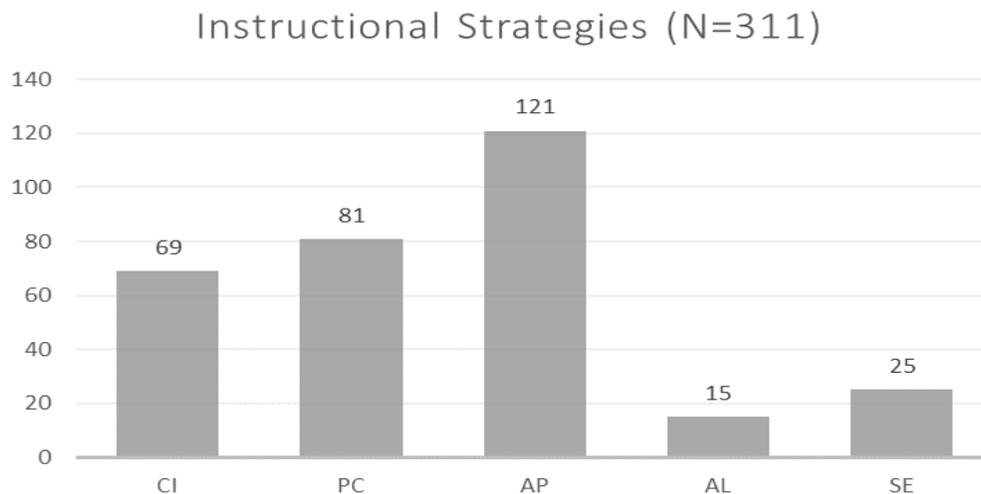
Figure 2

Distribution of OER Types



Note: N indicates the number of codes.

Regarding instructional strategies and types of OER shared in an elementary STEM teachers' PLN, teachers sought ideas about activating learner processing of instruction (N=121, 38.9%), such as effective learning activities for seasonal themes or topics for meaningful questions to facilitate students' cognitive processes (See Figure 3). For instance, a user shared a representative discourse of activating the process of learning by sharing, "I've been using it with 5th graders on the first day of our weekly rotation this month, then they choose a STEM challenge based upon what inspired them from the film." Strategies for presenting content (N=81, 26.0%) were followed by showing messages about how to provide examples or learning materials. However, discussing methods or experiences for assessing students' learning was rarely presented (N=15, 4.8%).

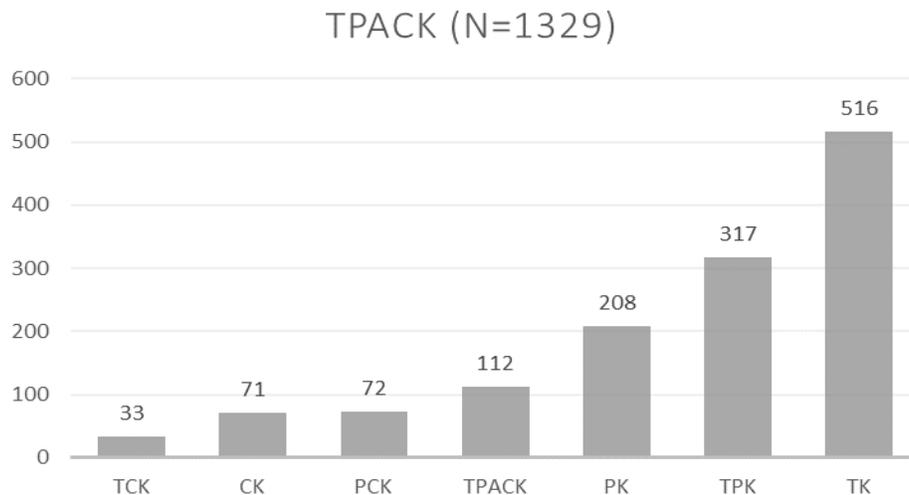
Figure 3*Distribution of Instructional Strategies*

Note: N indicates the number of codes.

RQ2. What Types of TPACK Do Elementary STEM Teachers Mainly Discuss in a PLN?

In terms of TPACK, Technological Knowledge (TK) was the most frequently discussed (N=516, 38.8%), followed by Technological and Pedagogical Knowledge (TPK) (N=317, 23.9%). On the other hand, Technological Content Knowledge (TCK) was the least shared type of TPACK (N=33, 2.5%). In other words, elementary STEM teachers in the PLN we examined sought ideas and shared knowledge or information on how to implement technologies for pedagogical usages, such as different learning activities based on age or tech savviness. (See Figure 4)

Figure 4*Distribution of TPACK*



Note: N indicates the number of codes.

RQ3. What Are the Relationships Between the Types of OER and TPACK in an Elementary STEM Teachers' PLN?

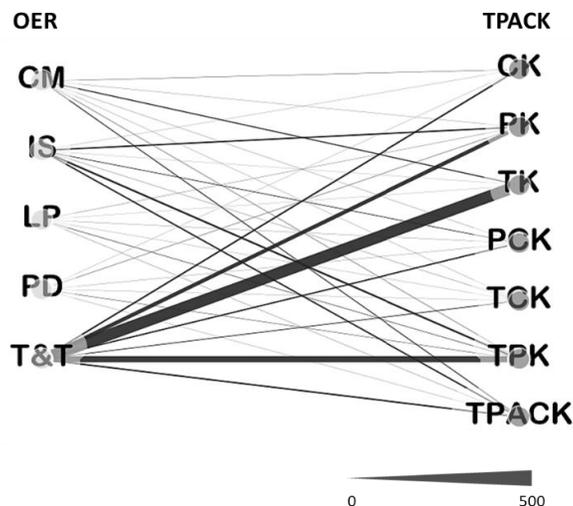
Figure 5 presents the associations between OER and TPACK in a network highlighting the weight of edges. The weight of edges is the summed frequency that edges traversed between a pair of nodes; thus, a thicker edge represents a stronger association of a type of OER and a component of TPACK. The relationship between tools and tips and Technological Knowledge (TK) showed the highest level of the weight of edges (N=477, 32.7%), indicating that teachers mainly discussed knowledge or skills of what technologies are available or how to use specific technologies in the classroom teaching.

One comment revealed the relationship between tools and tips and TK: “For some bottle caps, just pushing strongly, straight down, with a Phillips head screwdriver works. Then you can size the tool to match your skewers or axles. I always put cardboard underneath to protect the table or floor.”

Messages relating to tools and tips and TPK were as follows (N=252, 17.3%), which means teachers shared how to apply technologies in teaching and learning activities.

Figure 5

Relationships Between OER Types and TPACK



Discussion and Implications

This study aimed to explore what types of OER and knowledge domains elementary STEM teachers shared in a space for informal professional learning and the relationships between OER and TPACK. By applying the qualitative content analysis method, we found that elementary STEM teachers shared techniques, such as tools and tips to apply to teaching the most, and technology-related knowledge and ideas to apply technology to their teaching were the major domains. Finally, elementary STEM teachers in a PLN shared resources on how to use technology more than any other knowledge domain for teaching.

RQ1. What are the dominant Open Educational Resources (OER) types in a Professional Learning Network (PLN) for elementary STEM teachers?

Across five different types of OER, we observed that elementary STEM teachers' OER in a PLN mainly focused on two types of OER: tools and tips (74.3%) and instructional strategies (14.6%). The study's findings support teachers' interest in learning about different resources and advice. Considering the nature of STEM education that aims to integrate technologies (e.g., coding robots and 3D printers) into teaching practices, this dominance of tools and tips and associated instructional strategies makes sense because these include resources and advice that can be useful when elementary STEM teachers employ technologies in their classrooms. Additionally, tools and tips can assist STEM instructors in providing their students with more differentiated and individualized learning experiences (Chaipidech et al., 2022; Moon & Park, 2021). For instance, by providing resources on various instructional strategies, assessment techniques, and adaptive technologies, teachers can better meet the diverse needs of their students and ensure that each learner is appropriately challenged and supported. These results are consistent with existing research, emphasizing the significance of practical resource sharing and instructional strategy exchange among teacher groups to promote a collaborative learning environment. (Trust et al., 2016).

RQ2. What types of TPACK do elementary STEM teachers mainly discuss in a PLN?

This study found that elementary STEM teachers in a PLN discussed TK and TPK the most, which is not in line with the previous studies showing that PK or PCK as dominant knowledge domains of STEM teachers in both formal and informal professional learning environments (Huang et al., 2022; Liljekvist et al., 2021; van Bommel et al., 2020). This result indicates that support for elementary STEM teachers' competencies can be different based on the nature of STEM education and teachers' contextual needs (Kast, 2020). Although developing interdisciplinary and cross-curricular learning tasks is demanding for elementary STEM teachers, they occasionally struggle with their interaction with technology, such as maintaining connections between smart devices and robots with too many students in a classroom (Burton, 2022). This finding shows the needs that existing studies addressed, such as more support in improving elementary STEM teachers' skills and knowledge of using appropriate technology along with their pedagogical and content knowledge (Hsu et al., 2011; Huang et al., 2022).

RQ3. What are the relationships between the types of OER and TPACK in an elementary STEM teachers' PLN?

The purpose of exploring the relationships between OER types and TPACK was to investigate what knowledge domains are associated with specific OER types as an in-depth analysis. The results showed that tools and tips and TK and TPK were strongly associated, meaning that elementary STEM teachers informally seek and share ideas or knowledge about technologies to learn technology itself or how to use specific technologies in classroom teaching. Honey et al. (2014) specifically identified three perspectives on technology in STEM education; the product of engineering; educational/instructional technology (e.g., clickers or SMART boards); and the tools of practitioners of the STEM field. Out of the three roles of technology in STEM education, the authors (Honey et al., 2014) emphasized the technology for practitioners (i.e., teachers) and consider it as the greatest potential to impact students' learning. Moreover, Hofer and Harris (2016) developed an OER-based teacher education program to help teachers' TPACK by insisting on more support of OER to assist teacher educators' efforts in critical ways.

Implications

Research Implications

This study has research implications for investigating what specific educational resources elementary STEM teachers sought and exploring distributions of their knowledge in an informal professional development space, which is still under-examined. The results of tools and tips and knowledge related to technology imply that researchers need to focus more on elementary teachers' realistic teaching contexts and suggest systematic support for technology integration (Kast, 2020). Since elementary school teachers are specialized in teaching multiple subjects, they

have to demonstrate teaching with more subjects than single-subject teachers. In other words, it is challenging for them to dive as deep into all subjects regarding overall content and pedagogical mastery. The barriers to the implementation of STEM for K-12 teachers include limited interdisciplinary knowledge, challenging situations of adjusting to the pedagogical principles and classroom roles, a lack of time and expertise in curriculum integration, and difficulties with assessments (Chai, 2019; Margot & Kettler, 2019). Those consistent voices from elementary STEM teachers reflect that researchers and teacher educators should design teacher preparation systems for technology integration before and after they become in-service teachers, such as providing a knowledge repository for STEM teachers with specific examples or ideas to implement STEM in teaching practice.

In PLNs for elementary STEM teachers, suggestions of instructional design or sharing experiences of instructional design for teaching STEM can be useful resources (Arshavskaya, 2019). This type of OER can be connected to Open Educational Practices (OEP) on how to adopt intellectual resources (i.e., instructional strategies) into instructional practices. Wiley et al. (2017) insisted that the sustainability of OER in K-12 settings is promising through empowering both teachers and learners as content creators or curators. Tang et al. (2020) also demonstrated the need to promote teachers' consolidation of selecting, using, and revising OER tailored to their instructional/learning contexts in their investigation of teachers' attitudes towards OER and perceived usefulness. Further examinations are necessary to uncover how elementary STEM teachers transfer various OER materials they acquire from their PLNs into their practices.

Design Implications

The current study's findings have important implications for PLN design. First, the results emphasize the significance of incorporating various types of OER, specifically tools and tips, into professional development programs for STEM teachers. The findings demonstrate a strong relationship between tools, tips, and technological knowledge. This highlights the necessity for STEM teachers to have access to resources that can assist them in effectively integrating technology into their teaching practices. In a PLN system, we could consider curating a diverse collection of OER that covers a wide range of tools and tips, addressing various aspects of technology integration in K-12 education (Tang, 2020). Additionally, it is valuable to encourage teachers' collaboration and knowledge-sharing through informal peer groups in PLNs by hosting regular virtual meetups or initiating collaborative projects. Furthermore, it is beneficial to provide microlearning resources (Word & Dennen, 2020) that offer bite-sized learning materials (e.g., videos and blog posts) to enable educators to quickly grasp insights on technology integration.

Limitations and Conclusion

There are limitations of the present study. While our study provides valuable insights into elementary STEM teachers' OER and TPACK in a PLN as informal professional development, it's important to acknowledge certain methodological limitations. The use of one case may have introduced selection bias, potentially limiting the generalizability of our findings to broader populations (Stake, 2006). Future studies could address these limitations by employing diverse cases. Despite these constraints, our approach allowed us to present an overview of elementary

STEM teachers' informal professional development on teaching practices and TPACK through interactions with OER, providing a foundation for future research in this area. Second, the current study did not examine how teachers' use of OER and TPACK varies across different grade levels or particular subject areas. There is also little examination on how instructors' OER and TPACK manifest themselves at various stages of their careers. Understanding these elements could give insights to educational institutions and lawmakers in creating tailored support and intervention strategies to improve teachers' knowledge of OER and practices in technology integration.

The current study investigated how elementary STEM teachers explored OER that were aligned with different TPACKs inside a PLN. In particular, we discovered that elementary STEM teachers primarily share tools and tips, and instructional strategies as OER, whereas TK and TPK are the most often discussed TPACK domains. Additionally, the study identified a close connection between TK and TPK and tools and tips, revealing that these teachers actively seek out and exchange knowledge or concepts about using technology in their classroom during a PLN. We hope that the current study results are informative to various stakeholders to shed light on creating PLNs and teacher development programs that enhance teachers' TPACK.

Acknowledgement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

- Almendro, D., & Silveira, I. F. (2018). Quality assurance for open educational resources: The OER Trust framework. *International Journal of Learning, Teaching and Educational Research*, 17(3), 1-14. <https://doi.org/10.26803/ijlter.17.3.1>
- Arshavskaya, E. (2019). Teachers' stories about teaching: Collaborative dialogues as open educational resources. *Journal on Empowering Teaching Excellence*, 3(1). <https://doi.org/10.26077/k1s8-jn09>
- Aslam, F., Adefila, A., & Bagiya, Y. (2018). STEM outreach activities: An approach to teachers' professional development. *Journal of Education for Teaching*, 44(1), 58-70. <https://doi.org/10.1080/02607476.2018.1422618>
- Assarroudi, A., Heshmati Nabavi, F., Armat, M. R., Ebadi, A., & Vaismoradi, M. (2018). Directed qualitative content analysis: The description and elaboration of its underpinning methods and data analysis process. *Journal of Research in Nursing*, 23(1), 42-55. <https://doi.org/10.1177/1744987117741667>
- Bastian, M., Heymann, S., & Jacomy, M. (2009). Gephi: An open-source software for exploring and manipulating networks. In *Proceedings of the international AAAI conference on web and social media*, 3(1), 361-362. <https://doi.org/10.1609/icwsm.v3i1.13937>
- Beach, P. (2018). Examining elementary teachers' use of online learning environments: An exploratory study. *Journal of Research on Technology in Education*, 50(1), 34-47. <https://doi.org/10.1080/15391523.2017.1383216>
- Beaven, T., (2018). "Dark reuse": An empirical study of teachers' OER engagement. *Open Praxis*, 10(4), 377-391. <https://www.learntechlib.org/p/207177/>
- Bencheva, N. (2020). *Open Educational Resources enhance the STEAM education*. Proceedings of University of Ruse, 58, 32-36. <https://conf.uni-ruse.bg/bg/docs/cp19/3.2/3.2-3.pdf>
- Burton, M. (2022). STEM teaching experiences: Impacting elementary teacher candidates' perceptions of teaching mathematics. *Investigations in Mathematics Learning*, 14(1), 14-27. <https://doi.org/10.1080/19477503.2021.2023967>
- Butcher, N., & Moore, A. (2015). *Understanding open educational resources*. Commonwealth of Learning (COL). <https://doi.org/10.56059/11599/1013>
- Carpenter, J. P., & Krutka, D. G. (2015). Engagement through microblogging: Educator professional development via Twitter. *Professional Development in Education*, 41(4), 707-728. <https://doi.org/10.1080/19415257.2014.939294>
- Carpenter, J., & Krutka, D. (2016). PK-12 teachers' conceptualizations of professional learning networks. In *Society for Information Technology & Teacher Education International*

- Conference* (pp. 1936-1942). Association for the Advancement of Computing in Education (AACE). Available from <https://www.learntechlib.org/primary/p/171954/>
- Chai, C. S. (2019). Teacher professional development for science, technology, engineering and mathematics (STEM) education: A review from the perspectives of technological pedagogical content (TPACK). *The Asia-Pacific Education Researcher*, 28(1), 5-13. <https://doi.org/10.1007/s40299-018-0400-7>
- Chaipidech, P., Srisawasdi, N., Kajornmanee, T., & Chaipah, K. (2022). A personalized learning system-supported professional training model for teachers' TPACK development. *Computers and Education: Artificial Intelligence*, 3, 100064. <https://doi.org/10.1016/j.caeai.2022.100064>
- Cole, F. L. (1988). Content analysis: Process and application. *Clinical Nurse Specialist*, 2(1), 53-57.
- Davis, T. (2013). Building and using a personal/professional learning network with social media. *The Journal of Research in Business Education*, 55(1), 1-13. <https://www.proquest.com/docview/1543749532?accountid=4840>
- Geng, J., Jong, M. S. Y., & Chai, C. S. (2019). Hong Kong teachers' self-efficacy and concerns about STEM education. *The Asia-Pacific Education Researcher*, 28, 35-45. <https://doi.org/10.1007/s40299-018-0414-1>
- Harris, J. (2008). TPCK in in-service education: Assisting experienced teachers' "planned improvisations." In AACTE Committee on Innovation and Technology (Eds.), *The handbook of technological pedagogical content knowledge for teaching and teacher educators* (pp. 251-271). Lawrence Erlbaum Associates.
- Hass M., Haley K., Nagappan B., Ankel F. (2020). The connected educator: Personal learning networks. *The Clinical Teachers' Toolbox*, 17, 1-5. <https://doi-org.ezproxy.csu.edu.au/10.1111/tct.13146>
- Hewlett Foundation. (2015). Open Educational Resources. Advancing widespread adoption to improve instruction and learning. <https://hewlett.org/wp-content/uploads/2017/02/OER-strategy-memo.pdf>
- Hofer, M., & Harris, J. (2016). Open educational resources (OERs) for TPACK development. In *Society for Information Technology & Teacher Education International Conference* (pp. 2872-2877). Association for the Advancement of Computing in Education (AACE).
- Honey, M., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research (pdf version)*. <https://doi.org/10.17226/18612>

- Hsu, M., Purzer, S., & Cardella, M. E. (2011). Elementary teachers' views about teaching design, engineering, and technology. *Journal of Pre-College Engineering Education Research (J-PEER)*, 1(2). <https://doi.org/10.5703/1288284314639>
- Huang, B., Jong, M. S. Y., Tu, Y. F., Hwang, G. J., Chai, C. S., & Jiang, M. Y. C. (2022). Trends and exemplary practices of STEM teacher professional development programs in K-12 contexts: A systematic review of empirical studies. *Computers & Education*, 104577 <https://doi.org/10.1016/j.compedu.2022.104577>
- Kast, D. J. (2020). *Addressing systemic challenges in elementary-school teacher preparation in science, technology, engineering, and mathematics*. [Doctoral dissertation, University of Southern California].
- Kimmons, R. (2015). OER quality and adaptation in K-12: Comparing teacher evaluations of copyright-restricted, open, and open/adapted textbooks. *International Review of Research in Open and Distributed Learning*, 16(5), 39-57. <https://doi.org/10.19173/irrodl.v16i5.2341>
- Kimmons, R. (2016). Expansive openness in teacher practice. *Teachers College Record*, 118(9), 1-34.
- 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>
- Krutka, D. G., Carpenter, J. P., & Trust, T., (2017). Enriching professional learning networks: A framework for identification, reflection, and intention. *TechTrends*, 61(3), 246-252. <https://doi.org/10.1007/s11528-016-0141-5>
- Jonassen, D.H., Grabinger, R.S., & Harris, N.D.C. (1991). Analyzing and selecting instructional strategies and tactics. *Performance Improvement Quarterly*, 4(2), 77-97. <https://doi.org/10.1111/j.1937-8327.1991.tb00505.x>
- Lave, J. & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.
- Lesseig, K., Nelson, T. H., Slavit, D., & Seidel, R. A. (2016). Supporting middle school teachers' implementation of STEM design challenges. *School Science and Mathematics*, 116(4), 177-188. <https://doi.org/10.1111/ssm.12172>
- Liljekvist, Y. E., Randahl, A. C., van Bommel, J., & Olin-Scheller, C. (2021). Facebook for professional development: Pedagogical content knowledge in the centre of teachers' online communities. *Scandinavian Journal of Educational Research*, 65(5), 723-735. <https://doi.org/10.1080/00313831.2020.1754900>

- Macià, M., & García, I. (2016). Informal online communities and networks as a source of teacher professional development: A review. *Teaching and Teacher Education*, 55, 291-307. <https://doi.org/10.1016/j.tate.2016.01.021>
- Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, 6(1), 1-16. <https://doi.org/10.1186/s40594-018-0151-2>
- Mishra, P., & Koehler, M. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017–1054.
- Monjelat, N., & Lantz-Andersson, A. (2020). Teachers' narrative of learning to program in a professional development effort and the relation to the rhetoric of computational thinking. *Education and Information Technologies*, 25(3), 2175-2200. <https://doi.org/10.1007/s10639-019-10048-8>
- Moon, J., & Park, Y. (2021). A scoping review on Open Educational Resources to support interactions of learners with disabilities. *The International Review of Research in Open and Distributed Learning*, 22(2), 314–341. <https://doi.org/10.19173/irrodl.v22i1.5110>
- Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and Teacher Education*, 21(5), 509-523. <https://doi.org/10.1016/j.tate.2005.03.006>
- Nochumson, T. C. (2019). Elementary school teachers' use of Twitter: Exploring the implications of learning through online social media. *Professional Development in Education*. <https://doi.org/10.1080/19415257.2019.1585382>
- Oddone, K., Hughes, H., & Lupton, M. (2019). Teachers as connected professionals: A model to support professional learning through personal learning networks. *The International Review of Research in Open and Distributed Learning*, 20(3), 102-120. <https://doi.org/10.19173/irrodl.v20i4.4082>
- Parsons, S. A., Hutchison, A. C., Hall, L. A., Parsons, A. W., Ives, S. T., & Leggett, A. B. (2019). US teachers' perceptions of online professional development. *Teaching and Teacher Education*, 82(1), 33-42. <https://doi.org/10.1016/j.tate.2019.03.006>
- Pawlowski, J. M., & Bick, M. (2012). Open educational resources. *Business & Information System Engineering*, 4(4), 209–212. <https://doi.org/10.1007/s12599-012-0219-3>
- Pelton, A. (2018). *The perceived influence of STEM-related online professional development on teacher's STEM content and self-efficacy*. [Doctoral dissertation, Northcentral University].

- Polgampala, A. S. V., Shen, H., & Huang, F. (2017). STEM teacher education and professional development and training: Challenges and trends. *American Journal of Applied Psychology*, 6(5), 93-97. <https://doi.org/10.11648/j.ajap.20170605.12>
- Rosenberg, J. M., & Koehler, M. J. (2015). Context and technological pedagogical content knowledge (TPACK): A systematic review. *Journal of Research on Technology in Education*, 47(3), 186-210. <https://doi.org/10.1080/15391523.2015.1052663>
- Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2), 4-14. <http://www.jstor.org/stable/1175860>
- Stake, R. E. (2006). *Multiple case study analysis*. Guilford.
- Tang, H. (2020). A qualitative inquiry of k–12 teachers’ experience with open educational practices: Perceived benefits and barriers of implementing open educational resources. *International Review of Research in Open and Distributed Learning*, 21(3), 211-229. <https://doi.org/10.19173/irrodl.v21i3.4750>
- Tang, H., Lin, Y. J., & Qian, Y. (2020). Understanding K-12 teachers’ intention to adopt open educational resources: A mixed methods inquiry. *British Journal of Educational Technology*, 51(6), 2558-2572. <https://doi.org/10.1111/bjet.12937>
- Teo, T. W., & Ke, K. J. (2014). Challenges in STEM teaching: Implication for preservice and inservice teacher education program. *Theory into Practice*, 53(1), 18-24. <https://doi.org/10.1080/00405841.2014.862116>
- Trust, T. (2017). Using cultural historical activity theory to examine how teachers seek and share knowledge in a peer-to-peer professional development network. *Australasian Journal of Educational Technology*, 33(1), 98-113. <https://doi.org/10.14742/ajet.2593>
- Trust, T., Krutka, D. G., & Carpenter, J. P. (2016). “Together we are better”: Professional learning networks for teachers. *Computers & Education*, 102, 15-34. <http://dx.doi.org/10.1016/j.compedu.2016.06.007>
- Van Bommel, J., Randahl, A. C., Liljekvist, Y., & Ruthven, K. (2020). Tracing teachers’ transformation of knowledge in social media. *Teaching and Teacher Education*, 87, 1-9. <https://doi.org/10.1016/j.tate.2019.102958>
- Vears, D. F., & Gillam, L. (2022). Inductive content analysis: A guide for beginning qualitative researchers. *Focus on Health Professional Education: A Multi-disciplinary Journal*, 23(1), 111-127. <https://search.informit.org/doi/10.3316/informit.455663644555599>
- Wiley, D., Webb, A., Weston, S., & Tonks, D. (2017). A preliminary exploration of the relationships between student-created OER, sustainability, and students’ success. *The International Review of Research in Open and Distributed Learning*, 18(4), 60–69. <https://doi.org/10.19173/irrodl.v18i4.3022>

- Word, K., & Dennen, V. P. (2021). *Sharing microlearning materials as open educational resources (OER)*. In J. R. Corbeil, B. H. Khan, & M. E. Corbeil (Eds.), *Microlearning in the digital age: The design and delivery of learning in snippets* (pp. 200-213). Routledge.
- Yassin, E., & Jung, I. (2021). Pedagogical purposes of using open educational resources in STEM education: A case study in a STEM high school in Egypt. *International Journal on Open and Distance E-Learning*, 7(2).
<https://ijodel.upou.edu.ph/index.php/ijodel/article/view/46>
- Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Sage.
- Zhang, S., Liu, Q. & Cai, Z. (2019). Exploring primary school teachers' technological pedagogical content knowledge (TPACK) in online collaborative discourse: An epistemic network analysis. *British Journal of Educational Technology*, 50, 3437-3455.
<https://doi.org/10.1111/bjet.12751>