Anderson, R. K., & Williams, M. (2023). Mathematics teachers' participatory patterns between face-to-face and virtual professional learning environments. *Contemporary Issues in Technology and Teacher Education, 23*(1), 24-47.

Mathematics Teachers' Participatory Patterns Between Face-to-Face and Virtual Professional Learning Environments

Robin Keturah Anderson and Martia Williams
North Carolina State University

This article reports on how mathematics teachers connect face-to-face and virtual professional learning communities by expanding the notion of lurker and broker within both environments. Through an analysis of 18 interviews with K-12 mathematics teachers, categories of participation are presented to describe the nuances between the ways mathematics teachers connect learning experiences across learning environments. This article provides examples of the ways mathematics teachers leverage learning within one space to broker information in the other. Methodological and practical implications of this research are discussed. Methodologically, this article presents the usage of artifact-stimulated recall during interviews to promote reflection of virtual learning interactions. Practically, this article seeks to push the field of mathematics teacher's professional learning beyond traditional forms of learning to see the value of informal learning in virtual spaces.

Mathematics teacher professional development often occurs through three formats: professional learning communities, coaching, or workshops. In a recent white paper, Slama et al. (2021) referred to this trifecta as the "steady state" of mathematics teacher learning, implying that most of the field creates learning opportunities for mathematics teachers this way (p. 6). According to the authors, little evidence supports the assertion that these methods increase student performance. In fact, Salma et al. found that teachers do not see these learning opportunities as being valuable to themselves or their students' mathematical performance.

While their report problematized the effect of individual professional development formats, Slama et al. (2021) found that comprehensive programs, which include more than one format along with intentional support, can improve student learning. This small glimmer of positivity in an overly dismal report on mathematics teacher learning, however, relies on a great amount of monetary and human resources. What can a district, or even an individual teacher, do to push beyond the steady state of teacher learning opportunities with the intention of improving student learning without the necessary resources? Slama et al. recommended a new direction for the field, one that centers the teacher within the learning experience.

In proposing a new direction for the field, Slama et al. (2021) encouraged future research to look into teacher-led professional learning innovations, specifically noting the success of organizations like The Global Math Department or active Twitter hashtags like #MTBoS or #iteachmath. The ubiquitous use of personal social media amongst the latest generation of teachers allows them to seamlessly adopt social media for professional purposes (Gurjar & Sivo, 2022). Social media platforms are, thus, perfect places to study teacher-led professional learning.

Within these social media spaces, teachers post questions and find resources to support their teaching practices (Macià & García, 2016). Teachers also propose topics of conversation and lead the direction of the discussion (Cansoy, 2017). These seemingly unstructured spaces are manipulated by teachers to provide the support they seek. Social media spaces are perfect locations for teacher-led professional learning innovations called for by Slama et al. (2021).

With the goal to better understand how online teacher-led opportunities are influenced by and have an impact on face-to-face (F2F) professional communities, we sought to better understand how teachers use social media spaces to learn. This study, situated within one Facebook (FB) group of mathematics teachers, expanded the definition of mathematics teacher learning by articulating how teachers position themselves as learners within these connected spaces (virtual and F2F). Building from the current literature on online teacher learning and online interaction research, our study was guided by the following research question: When mathematics teachers seek professional learning online, what connections exist between their virtual and F2F contexts?

Literature Review

This section presents a brief overview of the research areas that connected with this study. The literature on online teacher learning is described, then, common patterns in how people choose to interact in online communities are summarized. Finally, mathematics teacher learning in virtual settings is described.

Understanding Teacher Learning Processes Online

The study of teacher learning must account for the location of a learning experience. Accounting for learning location allows researchers to study

and make hypotheses regarding how differences in learning location impact teacher professional learning. Teachers gravitate to online platforms as one location for their learning opportunities. Many studies have focused on interactions among teachers on platforms, such as Facebook (Anderson et al., 2022; Kelly & Antonio, 2016; Liljekvist et al., 2017, 2021; Lundin et al., 2020; Mansour, 2020; Robson 2018; Tour, 2017; van Bommel et al., 2020), Twitter (Gruzd et al., 2016; Parsons et al., 2019; Tour, 2017), Edmodo (Trust, 2016; 2017), and Pinterest (Hu et al., 2018). Others have analyzed university supported platforms (Kent et al., 2019), or platforms created by researchers (Kumar, 2019; Li et al., 2020; Qian et al., 2018; Tsiotakis & Jimoyiannis, 2016).

Most of these platforms support learning "outside formally structured, institutionally sponsored, classroom-based activities" often referred to as informal learning (Watkins & Marsick, 1992, p. 288). To move beyond the study of traditional locations of learning, such as school-sponsored professional development or university-based courses, researchers are beginning to study diverse locations, with online platforms being one of the new locations facilitating learning amongst teachers.

When studying these online platforms, researchers have drawn upon different methods to analyze teacher learning processes online. Some researchers have adopted methods that facilitate the analysis of conversations between teachers on their chosen platform (Cansoy, 2017; Gruzd et al., 2016; Kelly & Antonio, 2016; Kent et al., 2019; Kumar, 2019; Li et al., 2020; Lundin et al., 2020; Schlager, et al., 2009). Other researchers have chosen to interview or survey teachers based on their online interactions (Carpenter & Linton, 2018; Hu et al., 2018; Mansour, 2020; Parsons et al., 2019; Qian, et al., 2018; Robson, 2018; Tour, 2017; Trust, 2016; 2017; Tsiotakis & Jimoyiannis, 2016). Using their analyses, researchers have made conjectures about participation patterns of teachers in online learning spaces.

While participation patterns online can mimic informal in-person interactions, some studies have hypothesized that online networks increase teachers' access to diverse perspectives (Carpenter & Krutka, 2015; Li et al., 2020; Macià & García, 2018; Trust, 2017). These online networks have often been described as virtual professional learning communities (PLCs), professional learning networks (PLNs), or more specifically, professional development networks (PDNs; Carpenter & Linton, 2018; Tour, 2017).

Within these online networks, teachers ask questions, gain ideas from others, and in some cases, build relationships providing them access to a wealth of information (Macià & García, 2016). Trust (2017) investigated how participation in an Edmodo mathematics subject community shaped mathematics educators' learning and practice. Through analysis of survey and interview data, Trust attributed mathematics teachers' participation within the diverse online community to their motivation to learn. The teachers reported that their participation allowed them to feel more confident and make changes to their practice.

The downside to online spaces is the lack of F2F interaction. Many teachers prefer the in-person format or a combination of F2F and virtual

interaction (Carpenter & Krutka, 2015; Carpenter & Linton, 2018; Macià & García, 2018; Parsons et al., 2019; Tour, 2017). Teachers have reportedly missed the in-depth discussions that happen through F2F interactions. Teachers have said that online platforms do not make in-depth discussion possible or that the only way these conversations can be possible is alongside in-person meetings.

Liljekvist et al. (2021) studied interaction patterns within self-organized mathematics education FB groups and concluded that participants tended to share knowledge, give advice, and seek support around important issues of teaching mathematics. These interaction patterns were often limited to questions with offered advice, rather than interactions developing into lengthy discussions. Liljekvist et al. likened these shorter question and advice exchanges to staff room interactions that occur informally between teachers at a school site.

Although these concerns about online communities are present, teachers have continued to create PLNs. According to Tour (2017), a PLN is an "informal learning network of teachers who communicate and collaborate online for professional purposes" (p. 180). Tour analyzed three teachers' PLNs and noted the major factors that made them want to continue to participate in these PLNs, as well as how they chose to interact in their PLNs with other teachers. One teacher stated that "it's my best professional learning I have ever done!" in reference to the PLN that she formed on Twitter (Tour, 2017, p. 183).

In terms of developing these PLNs, based on Tour's study, teachers search the internet for articles and resources that would be helpful and join the learning communities that they find through these searches. Teachers have said that these places provide a wealth of information that they can save and use to collect data in various forms to use for classroom application (Tour, 2017). Teachers created PLNs by accessing information on multiple virtual platforms, some with static resources (e.g., blogs) and others with groups of teachers actively discussing content (e.g., FB discussions). While studies have investigated the creation, and benefit, of PLNs, the field of teacher learning has just begun to examine how the connection between virtual PLNs and F2F networks influence learning opportunities.

Describing Engagement in Online Learning Communities

Engagement in online learning communities assumes different forms. Two major categories of ways teachers interact have emerged through the study of online learning communities. The first category, lurkers, is defined as "those who read postings without making their own contribution" (Nguyen, 2020, p. 2). The second category, brokers, have been described in different forms in various studies, such as bridges (Macià & García, 2018) or posters (Amichai-Hamburger et al., 2016; Nguyen, 2020). For the purposes of this article, we use the term broker to describe members who "are more participative, engaged and help to spread information throughout the network" (Macià & García, 2018, p. 1).

Individuals are often called lurkers due to their silent observation of the group and minimal posting (Shafie et al., 2016). Lurkers sustain membership in these groups by observing interactions. Within both large and small online communities, lurkers are assumed to be a majority of participants, with researchers referencing the 90-9-1 rule for large, open communities – 90% of participants lurk, 9% contribute occasionally, and 1% contribute a majority of the content (Cranefield et al., 2015; Marett & Joshi, 2009; Nielsen, 2006) – or the 50-30-20 rule for smaller, bounded communities – 50% of participants lurk, 30% contribute occasionally, and 20% contribute a majority of the content (Brandtzaeg & Heim, 2011).

Research on lurking has uncovered many reasons why individuals lurk within learning communities: free-riding (Kollock & Smith, 1996), microlearning (Kahnwald & Köhler, 2006), and knowledge sharing barriers (Ardichvilli, 2008; Preece et al., 2004). These studies have helped expand the field's understanding of lurking teachers within virtual learning environments. Lurking teachers, while motivated to not participate for a variety of reasons, often sustain membership within virtual communities because of a desire to learn.

Teachers who are members of distinctly different learning communities and share information between the two communities are referred to as brokers (Carpenter & Linton, 2018; Wenger, 1998). A broker is an individual who can be an active member of both communities and translates knowledge from one community to the other. A member who acts as a broker enters communities with the intention of finding resources to support the development of their peers. A teacher who acts as a broker can broker knowledge between two online communities or from their F2F community to an online learning community. For the purposes of this study, a teacher who shares knowledge between two communities, regardless of the direction, is considered a broker.

Mathematics Teacher in Online Learning Communities

Researchers who have specifically looked at mathematics teachers' usage of social media support the claims made by other scholars, such as the advantages of using mathematics-specific Twitter hashtags to ask for and provide support through virtual mentoring (Parrish, 2017), and describing online spaces as communities of practice (Risser & Bottoms, 2018). More specifically, researchers have found that virtual learning communities allowed mathematics teachers to access a wide variety of resources to support their teaching (Shapiro et al., 2019). Through their analysis of Pinterest posts, Shapiro et al. concluded that elementary mathematics teachers continually made complex decisions about which resources would be best. These types of complex decisions were also made through discussions within FB groups (van Bommel et al., 2020) and within Twitter threads (Larsen & Parrish, 2019).

Mathematics specific topics discussed online have ranged from supporting students within heterogeneous mathematics learning opportunities (Anderson et al., 2022) to the discussion of cognitively demanding tasks (Parrish, 2016). While mathematics teachers within social media tend to have the same participatory patterns as other teachers, they differ because

their motivations to go online are often unique to mathematics and necessitate studying them apart from general teacher learning online.

While it is clear why mathematics teachers are entering online communities to learn and how they are participating once they enter these communities, it is less clear how their virtual and F2F opportunities influence each other. Understanding the relationship between a mathematics teacher's virtual and F2F communities could provide the field with a better understanding of mathematics teacher learning to help move past the steady state of what is currently offered within the field (Slama et al., 2021, p. 6). Thus, this study sought to report on the connections mathematics teachers make between these two communities and how they interact within them to further their professional learning and the professional learning of colleagues, both F2F and online.

Methodology

Setting

This research drew from a larger study that examined learning networks of mathematics teachers who participated in a closed mathematics education FB group. Eclipse (pseudonym), a university-based mathematics education research group, created this group in the summer of 2017. To become a member of the closed group, requestors responded "yes" to the following prompt:

By joining the group, you have access to resources, and act as a participant in our research of online learning networks. Type "YES" to agree to participate in the research. Only requesters who agreed to the research project were admitted to the group; therefore, every member of the group consented to be a part of the research study.

Eclipse staff members moderated the group. Moderators approved membership based on the answers to the stated question and infrequently held scheduled events to discuss the teaching and learning of mathematics. Moderators rarely participated in conversations but did so when they felt their expertise in mathematics education would add to the conversation. The authors of this paper were not moderators of the Eclipse FB group.

Members of the group often posted questions about mathematics education, shared struggles and success stories, and less frequently, posted links to articles around mathematics education. Over the course of the 12 months of data collection, the group averaged seven original posts, 95 comments, and 209 reactions a day. Reactions are the way group members can react to a post, or comment, without writing anything. Members reacted by clicking the like, love, ha-ha, sad, or angry emojis at the bottom of the post or comment. In general, activity within the group occurred daily through multiple forms of participation. At the time of data collection, there were 14,943 members of the Facebook group.

Participants

This article reports on an analysis of interview data from the larger study. The original study consisted of computational content analysis of posts, a survey, and interviews. The interview participants are a subset of the survey respondents. The sampling of the interview participants was a stratified random sample layered on a convenience sample. At first, the pool of potential interviewees was solicited through a question in the survey that asked for their contact information if they were interested in participating in a follow-up interview about their professional learning experiences. The initial sampling was classified as a convenience sample because it was based on teachers' self-selecting to participate in a follow-up interview.

Two hundred thirty-nine of the 322 survey respondents agreed to be interviewed. A stratified random sample was generated from the 239 respondents willing to be interviewed. The strata were created based on one free-response question in the survey. The survey question asked the respondents to describe why they search online to learn versus learning in F2F learning communities.

Open coding (Creswell & Poth, 2018), an emergent qualitative coding process where the researcher applies summary codes to the data that are not predefined, was used to create the strata. Twenty codes were originally generated, which were then organized around five themes (philosophy, isolation, convenience, community, and resources). Based on the percentage of survey respondents in each theme, the willing interview participants were randomly selected within those themes (or strata). Eighteen interviews were conducted. All interviewees self-identified as White, 17 identified as female, 13 had more than 15 years of teaching experience, 15 taught in the United States of America, and 13 taught in public schools with an even split between primary and secondary teaching for the participants. See Table 1 for individual interviewee demographic data.

Interview Description

The interview protocol was designed to add a rich description to how teachers used their PLNs to develop professionally. During these interviews, teachers were asked to share how they developed their network, how they prioritized their learning partners, and how they saw themselves as members of the FB learning community. For the sake of this article, we focused on the analysis of the final section of the interview pertaining to how they saw themselves as members of the FB learning community. This portion of the interview used an artifact-stimulated recall (Bloom, 1953) and a think-aloud during a live look-in at the FB group.

Table 1
Interviewee Demographic Summary

Name (pseudonym)	Gender	Years of Teaching	Grade Band	Type of School	Country
Davis	F	19	6-12	Public	USA
Finn	F	3	9-12	Private	USA
Cole	F	15	K-2	Private	USA
Roger	M	7	6-8	Private	Japan
Kupert	F	28	3-5	Public	USA
Longstrom	F	30	9-12	Private	Malawi
Tracy	F	18	3-8	Public	USA
Kraig	F	27	9-12	Public	USA
Elliot	F	15	9-12	Public	USA
Everton	F	20	3-5	Public	USA
Elms	F	13	3-8	Public	USA
Alberton	F	24	K-2	Public	USA
Milton	F	30	9-12	Private	Australia
Stuart	F	4	9-12	Public	USA
Desjardin	F	9	K-5	Public	USA
Morgan	F	18	3-5	Public	USA
Northman	F	17	9-12	Public	USA
Kline	F	37	3-5	Public	USA

Artifact-Stimulated Recall

Along with conducting a semistructured interview, interviewees participated in an artifact-stimulated recall (Bloom, 1953) during the interview. Artifact-simulated recall is an interview methodology that allows the interviewee to relive an event by experiencing the event again through artifacts such as audio, video, and written records. Bloom used artifact-stimulated recall with undergraduate students as a way to understand their thought processes during a university lecture.

The interview protocol for this study included artifact-stimulated recall so that participants could review their past FB participation and react to and reflect on the content. By using exact interactions, a better understanding of the reasons why they participated in the FB group and subsequent outcomes of the learning experiences can be discussed. For the interviewees who had posted or commented within the FB group the following artifact-stimulated recall structures were used:

1. Provide time for interviewee to review all of their interactions, with interactions being in a shareable online document;
2. Focus the interviewee on the post with the most interactions and allow them to review the post and all the comments; and
3. Ask the following questions:
4. Why did you choose to comment on this post?
    - How do you think your comment would help the original poster?

- Do you believe you learned anything from interacting in this post?
- What, if anything, surprised you within the interactions?

Live Look-In

The final part of the interview consisted of a 5-minute think-aloud as interviewees participated in a live look-in to the FB group. The think-aloud allowed us to observe, in real time, the interaction patterns of teachers as they participated within the FB group. This method was specifically used to capture the decision-making processes of members that did not actively post, which could be roughly 90% of members (Nielsen, 2006). The live look-in portion of the interview consisted of the following structure:

1. Interviewer shares computer screen over video conferencing platform with the Eclipse FB page's most recent interactions visible.
2. Have interviewee review the most recent post and ask, Does this original post interest you? Why or why not?
3. Have interviewee review the comments on the most recent post and ask, Now looking at the comments, does it interest you now?
4. Conclude the review of the top post by asking, Would you have participated in this discussion? Why or why not?
5. Repeat the above structure with the time remaining in the 5-minute live look-in portion of the interview.

This method provided access to the decision-making process experienced by teachers as they participated in an online learning community.

Interview Analysis

The analysis of the interviews began with in-depth memos immediately following each interview. A memo was generated based on answers provided by the interviewee. Each memo contained detailed notes about how the interviewee described their F2F professional development opportunities offered by their school site and what they pursued on their own. The memo also contained notes about the interviewee's online learning habits, their comparison of online learning to F2F learning, and their specific reflections on the Eclipse Facebook group. These memos became data sources that were coded initially in the analysis process.

Once the interviews were completed, the first round of coding occurred with the intention of understanding how teachers interacted within their complex learning networks. Open coding (Creswell & Poth, 2018) was used during the first pass to code instances of when the interviewee described how they interacted in their network. From the initial round of open coding, two themes emerged: Lurking Learner and Knowledge Broker.

After the initial generation of the two themes from the memos, the interviews were transcribed and coded. The two themes that were generated from the memos were applied to the interview transcripts. The codes were applied at the sentence level; therefore, both Lurking Learner and Knowledge Broker could be applied to the transcripts of individual

interviews. Thus, the interaction themes were not mutually exclusive, and an individual interviewee could be coded as more than one type of interactor, which produced the third theme: Hybrid Participant.

Once the interviews were coded with the three interaction themes, analytic memos were created. The analytic memos were detailed summaries of the themes which guided the reporting of the findings section.

Results

This section provides evidence to answer the research question, "When mathematics teachers seek professional learning online, what connections exist between their virtual and F2F contexts?" Findings are organized through the existing categories of lurker and broker. Then, we describe the analysis of the hybrid theme and propose the expansion of the lurker and broker categories of participation that leverages the nuances of virtual and F2F interaction patterns. All names mentioned are pseudonyms.

Defining and Identifying Lurkers and Brokers Online

Lurkers

In the context of the Eclipse Facebook group, lurkers are defined as those who do not contribute to the online environment through posts or comments. Typically, they only observe and might occasionally react to an existing post. Ten of 18 participants were categorized as lurkers. One interviewee playfully said, "My children call me a stalker because I like to just read, watch, and listen. I like things and will check out things that interest me. But I don't contribute by posting."

Among these lurkers, six reported not interacting on the FB page due to lack of time. One interviewee noted, "I think I don't want to really take the time. I'm more of a surfer. Does that make sense?" A majority of these lurkers, six of 10, were veteran teachers with more than 16 years of teaching experience, who claimed to lurk because they desired to stay up to date on current mathematics teaching practices.

Brokers

Brokers describe people who have a record of interaction on the Eclipse Facebook group through either posting, commenting, or both. Eight participants fell into that category. Many brokers either held a professional leadership role (three of eight), such as a mathematics coach or a department head, or had an informal leadership role (four of eight), where they chose to share information and resources with their peers without being required to do so. All of the brokers in this study participated in some form of sharing in virtual and F2F. Half of the brokers shared their own classroom experiences on the Eclipse FB group through posts or comments. Many brokers were motivated to share in this online community because of their desire to help other educators or share their exciting classroom experiences.

Expanding Beyond Lurker and Broker

While we identified participants who fit the previously defined online lurker and broker roles, in our analysis we also identified a relationship between the ways teachers chose to interact in online spaces, such as the Eclipse FB group, and how they interacted in professional development opportunities among their F2F colleagues. Our findings present these relationships between virtual and F2F communities through expanding the categories of broker and lurker to include a hybrid category, in which a mathematics teacher could participate in various ways across different settings.

The expanded categories use a few new terms: bidirectional, connector, and transitioner. Bidirectional is used to describe participants who participated similarly in their F2F and virtual professional environments. A bidirectional broker shared information online and in person. The second term, connector, collected information from one space and brought it to another. The F2F-Virtual Connector brought information from their F2F spaces to their virtual environments. The Virtual-F2F Connector took information from their virtual spaces to their F2F communities. Last, the transitioner category is one in which a person was transitioning between any of the categories. In what follows, each new category is described in detail using data to illustrate the interaction patterns.

Bidirectional Brokers

Bidirectional brokers transferred information from one space to another. Seven of the 18 participants fit the bidirectional broker category. These participants shared information in the Eclipse FB group that they had gathered from their classroom, other virtual spaces, or through their F2F professional development. The main goal of bidirectional brokers was to provide resources and support to other teachers in their online and F2F networks. Participants classified as bidirectional broker mentioned that they shared resources in Facebook groups, websites that they created, and through emails that they sent to in-person colleagues. Often, these participants either had formal leadership roles like a department head or mathematics coach or informal leadership roles that they chose to take on for themselves, such as an unofficial department head. A majority of the bidirectional brokers (five of seven) were formal or informal leaders in their schools.

Ms. Cole is an example of a bidirectional broker. She taught elementary school for 15 years in a small-town private school. She chose to learn online to reflect on her own practices and to read the content that is created by others. She also enjoyed the opportunity to reach a large network of people, obtain curriculum resources, and find a professional community because she felt that her school lacked mathematics professional development opportunities.

Ms. Cole is an example of a bidirectional broker because she both commented in the FB Group by posting activities that she had done in her classroom and distributed information she found in the FB group within her F2F communities. During the live look-in portion of her interview,

when asked if she would comment on the posts, Ms. Cole reflected, "If I had a contribution that I felt was a strategy for me that was successful. Probably, I would have to be pretty confident with it being a successful strategy and not just wishy-washy about it." Her reflection summarized that she was not just brokering any information, but rather information she was confident in.

Along with posting to the FB group, Ms. Cole sent out information that she had collected in her online learning to other teachers at her school. Ms. Cole was a broker from virtual to F2F when she noted,

> I got a lot of the teachers to do a [Eclipse activity] last year. I created a Google Drive with just links to websites that would be helpful in planning because I know that we don't have this time together.

Ms. Cole's brokering of information about the Eclipse activity, an online resource often discussed in the Eclipse group, illustrated how participants in the virtual learning space transferred information to their F2F colleagues. Her interactions online and F2F are an example of how a bidirectional broker moved information back and forth between online and F2F learning communities.

Connector

Connector is another category that extends beyond lurker and broker. We define two types of connectors: F2F-Virtual Connectors and Virtual-F2F Connectors. The difference between the two categories is the direction in which teachers gathered and shared information. Nine of the 18 participants fell into one of the connector classifications. Seven of the connectors were veteran teachers, and five connectors were leaders in their schools.

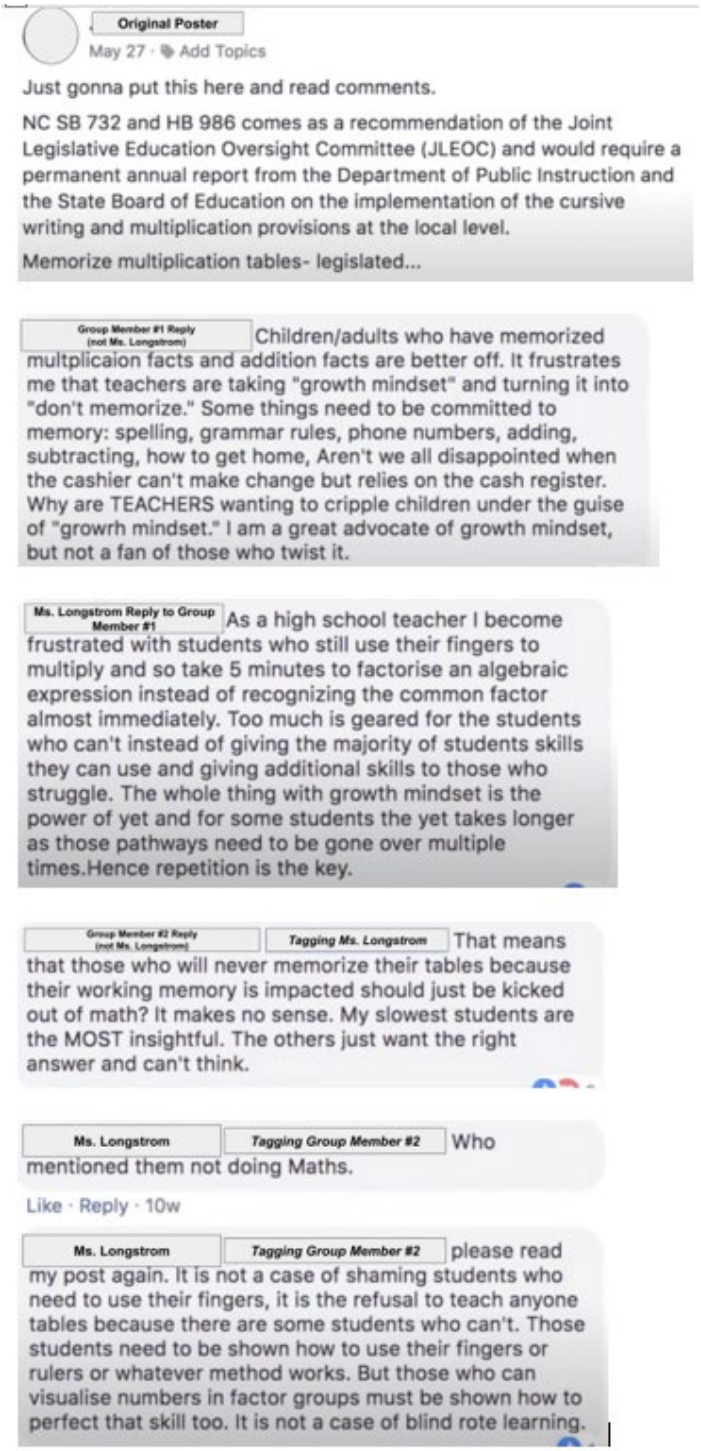
F2F-Virtual Connector. F2F-Virtual Connectors took information from their F2F learning environment and shared this information online. The online sharing may have taken place in the Eclipse FB group, or some other online space, or both. Only one participant, Ms. Longstrom, a private school teacher in Malawi, fits into this classification. She had taught for 30 years and stated that she had ideas and wisdom she had learned in F2F settings to share with other teachers online. Sharing online allowed her to challenge some ideas in the FB group because some members had misconceptions about growth mindset.

During the artifact-stimulated recall portion of her interview, Ms. Longstrom reviewed a post that had the group debating the memorization of multiplication facts. After reviewing the post (an abbreviated version is included in Figure 1, which contains her interactions within the post), Ms. Longstrom shared the following:

But one of the big problems that I have found with [Eclipse's] research is that when people read it, and they don't go through it, the whole thing, they don't understand the whole concept of neuroplasticity. They say, "Oh,

you mustn't teach anything in a rote manner. You must let them investigate everything."

Figure 1
Abbreviated Facebook Group Interaction



As her original interaction on this post indicated, Ms. Longstrom tried to deepen the group's understanding of growth mindset to include the processes of repeating content to strengthen pathways in the brain when she stated, "The whole thing with growth mindset is the power of yet and for some students the yet takes longer, as those pathways need to be gone over multiple times. Hence repetition is the key." Ms. Longstrom returned to the conversation to defend her support of memorizing mathematics facts when other group members questioned her intentions. She saw her participation in the group as a way of helping others through sharing her experiences and shining a critical lens on conversations. Ms. Longstrom, while active within the Eclipse Facebook group, did not bring information from the virtual setting to her F2F community because of a lack of time within the required professional development for teachers to share resources and ideas.

Virtual-F2F Connector. Virtual-F2F Connectors were the most common type of connector among the participants in our study. These educators took the information that they learned online, either in the Eclipse FB group or other virtual spaces, and brought that information back to their in-person colleagues. One participant reported they chose to lurk online because they liked having the opportunity to process the information they were accessing online and determine what was useful to share before bringing their online research to their F2F colleagues. Ms. Tracy, a Virtual-F2F connector, had taught middle and high school for 20 years in a suburban public school. She said she chose to go online because it gave her time to learn:

> While I do appreciate the face-to-face sessions, I guess another one of those disadvantages is that I feel like my processing time is slower and it often takes me longer than the time I'm given to really allow things to sink in. When I go online, I can look at it, I can come back to it as much as I need to, and I can save something. I can have access to it whenever I need to, rather than going, "I didn't get it the first time." It's a bit safer for me.

The ability to learn at her own pace and save information for later motivated Ms. Tracy to lurk within the Eclipse FB group. She gathered information for her own classroom and the teachers in her department due to her role as mathematics lead at her school. While she did not actively participate in the group, she did connect her F2F learning community with information she gathered online. In the following quotation, Ms. Tracy recounted a situation from the previous school year:

> In particular, as lead teachers last year for numeracy, we were all given a copy of Mathematical Mindsets. That's something that I had already been doing online. … Then, it became something that people had started mentioning, and I was able to say with my colleagues at school, Know that I've been doing this for a while. The board's getting behind it now and it's really good. They're embracing the growth mindset and trying to make that a really big part of what we do with our mathematics instruction." It was something that I already had experience with and then could bring to my colleagues face-to-face if that makes sense.

As a connector, Ms. Tracy provided her expertise to her F2F colleagues regarding Mathematical Mindsets, which she acquired in virtual learning environments.

Four of the eight virtual-F2F connectors were leaders in their schools. Two had a formal obligation to share information with colleagues as a part of their job responsibilities, while two others claimed to be informal leaders who desired to help their colleagues professionally develop. Ms. Davis, a 19-year veteran teaching secondary mathematics in a public school, said that, while she did not have a formal leadership position, in the past when she had "found cool articles … [she] printed them out and then put them in the teacher's lounge and maybe somebody else will read it."

Another participant with an informal leadership position, Ms. Alberton, often shared information over a text message group with her F2F colleagues: "I actually posted on Messenger about a virtual mathematics conference. … I share lots with them there. I love it." Of the participants who did not hold formal leadership positions, they claimed to share information from virtual spaces through informal means of communicating with colleagues, like the table in the teachers' lounge or a text message group outside of sponsored school communication.

Participants in formal leadership positions who were classified as Virtual-F2F connectors often created official communications to disseminate information. Ms. Milton, a numeracy coordinator at a private school in Australia, commented that she had multiple ways of connecting what she was learning virtually with her F2F community:

> I go to the website from the Facebook link, then I'll cut and paste it if I like it. So my OneNote is shared with all the maths teachers at school as well. So when it's updated, they see what I'm doing. … I have a Google classroom as well, just for the teachers, that I will put stuff in. And if I see them, I'll say, "Oh. I've put something in there for your Algebra class, or your coordinate geometry, or whatever it is."

These means of dissemination allowed leaders in formal roles to curate and archive information and resources they were finding in virtual spaces.

Transitioner

Transitioners are the last new category being introduced in this study. These participants were transitioning between two of the previously mentioned categories. Two participants in the study were coded as transitioners. For both educators that fit into this category, the change in their virtual interactions were influenced by changes in their F2F learning opportunities.

Ms. Elliot, a high school mathematics teacher that had taught for 15 years, claimed her reason for increasing her attention to the Eclipse FB group was to connect with other teachers who shared her teaching philosophy. According to Ms. Elliot, her new F2F colleagues did not share mathematics

ideas or care about trying new things in their classrooms. She explained why she chose to learn online:

> You get lots of ideas because different states just do things differently. I've seen that just from going from [previous teaching context] to [current teaching context]. You find people that you like their ideas and then you can follow them or look for their comments. Just getting outside your box. I even find it interesting to say, "I've never even thought of that." It just gives you new ways to look at things that you wouldn't get in a setting where all your teachers are pretty stagnant.

Ms. Elliot saw online communities, such as the Eclipse FB group, as an opportunity to reach a diverse group of teachers, which was not possible among her new F2F colleagues. When asked about her current colleagues and why she did not seek them out for professional learning opportunities, Ms. Elliot explained, "I go online because my colleagues either do not care or are not smart enough to go about different ideas." Her perception of her colleagues' lack of desire or ability to learn new practices initiated her transition from virtual-F2F connector to lurker.

During the artifact-stimulated recall portion of her interview, Ms. Elliot explained why her only interactions on posts occurred when she put an "F" in the comments. She first explained, "An F just means I'm following this post." After reading through the post, Ms. Elliot described why she wanted to follow the conversation, "Our Algebra 1 textbook in our school is horrendous. I was looking for just materials that I could use that would get me outside of my book. I'm guessing that's why I looked at it." Her usage of "F" to follow a conversation did not add to the FB group's understanding of the topic and should be viewed as a lurking interaction. Ms. Elliot simply used "F" instead of the bookmark function within the platform.

Through the artifact-stimulated recall, Ms. Elliot expanded on why she felt the need to bookmark the conversation. She attributed the reading and bookmarking of materials online to her desire to supplement her school's required, often unengaging, curriculum. Her new context, its resources, and the lack of learning opportunities with her F2F colleagues had transitioned Ms. Elliot to a lurker. Due to recently moving schools and a lack of data from the interview on the connections between her virtual and F2F learning environments, Ms. Elliot is considered a transitioner rather than one of the other three categories.

With further data collection, Ms. Elliot has the potential to fall into a fifth category that was not present in the data: bidirectional lurker. A bidirectional lurker could be someone who does not share within any learning space.

Discussion

The proposed classifications categories build on and extend previous literature on how individuals interact within online spaces. This research provides detail on how some teachers connect F2F and virtual communities. While the literature has strongly defined ways of interacting

online, specifically around lurkers (Ardichvilli, 2008; Kahnwald & Köhler, 2006; Preece et al., 2004) and brokers (Macià & García, 2018), the proposed expansion of categories provides detail on how virtual lurking and brokering can impact, or be impacted by, F2F interactions.

The four new categories are bidirectional broker, F2F-virtual connector, virtual-F2F connector, and transitioner. Within each of these new categories, we described patterns between interactions within virtual and F2F professional communities. These more nuanced definitions of how mathematics teachers are interacting virtually in conjunction with their F2F interactions enhance how researchers can define them as learners and their intentions for learning. These new categories provide the field of mathematics teacher learning new ways of defining, and thus investigating, teacher learning outside of traditional structures.

The interconnected nature between virtual learning and an individual's F2F professional community is a finding from this study that supports and extends the literature on teacher PLNs (Carpenter & Krutka, 2015; Carpenter & Linton, 2018; Macià & García, 2018; Parsons et al., 2019; Tour, 2017). Specifically, the findings support Trust et al.'s (2018) research on school leaders PLNs. Trust et al. highlighted the unique ways individuals who hold positions of leadership connect their virtual and F2F community. These obligations come from the need to learn diverse content to support multiple teachers at different grade levels. Since this type of diverse PD is often not available to leaders, they expand their PLNs to online spaces for these opportunities.

Our study extends recent research by conducting interviews with teachers who participated online to better understand how their learning online was influenced by, had an influence on, and was connected to, their F2F communities. We found a difference in brokering patterns between virtual-F2F connectors who hold formal positions of leadership and those who have informal leadership roles. Teachers in formal roles tended to share information found online over school-sponsored platforms like learning management systems or newsletters. Teachers who had informal leadership positions used fewer formal channels to communicate and, instead, used informal methods like messenger apps or printouts left in common areas.

The largest number of teachers in the study were classified as virtual-F2F connectors. This finding supports research finding that a majority of members of online groups do not participate, but rather lurk within the group (Cranefield et al., 2015; Marett & Joshi, 2009; Nielsen, 2006). Our findings, while they support that a majority of teachers lurk in online groups, also speak to the importance of these groups for the larger learning networks of these lurking teachers. While they do not share information online, these teachers classified as virtual-F2F connectors created pathways to acquire new information from virtual spaces into these F2F communities.

As discussed earlier, Ms. Milton brokered information from the FB group back to her F2F colleagues through both a OneNote document and a Google Classroom. The passive participation in the Eclipse FB group provided access to a reservoir of information that teachers could draw

upon to support their learning or the learning of others within the F2F network. These findings provide evidence of the benefit of membership in virtual communities, even if teachers are not actively participating by sharing within them.

The content that participants shared both virtually and F2F is worth noting and supports previous research on what content teachers seek out online (Parrish, 2016; Shapiro et al., 2019). Because the FB group was sponsored by the Eclipse research group, the connection to mathematics content often leaned toward ways the Eclipse group promoted equitable mathematics teaching. For example, Ms. Longstrom used learning from her F2F experiences to challenge how the group was misapplying the concept of neuroplasticity. Through this interaction, Ms. Longstrom helped the group interpret the concept of growth mindset through a mathematical lens.

Mathematics curriculum, whether general like Algebra 1 (Ms. Elliot's example) or specific like an Eclipse activity (Ms. Cole's example), was also a focus of the knowledge that teachers brokered between the virtual and F2F settings. Whether it is supporting the development of virtual community members' understanding of brain science or seeking equitable mathematics curriculum, this study adds to previous research on what knowledge teachers are seeking, and sharing, within virtual and F2F communities.

Implications

Methodologically, this study expands how researchers can understand participatory practices of teachers learning online and how teachers connect virtual and F2F communities. Recent research on online learning patterns of teachers have mostly drawn upon survey and content analysis on interactions (Carpenter & Linton, 2018; Hu et al., 2018; Mansour, 2020; Parsons et al., 2019; Qian, et al., 2018; Robson 2017; Tour, 2017; Trust, 2016; 2017; Tsiotakis & Jimoyiannis, 2016). This study expands these methodologies to use interviews with embedded artifact-stimulated recall and live look-in sessions to uncover more evidence of how and why teachers learn online. The use of artifact-stimulated recall within the interview allowed the teachers to reexperience the posts they had previously interacted in. The reexperiencing provided the teachers time to review previous interactions, which allowed them to link their reflections on learning within the Eclipse FB group to the ways they participated within the interactions.

By providing new content from the FB group during the live look-in portion of the interview, participants had the opportunity to expand upon their reasons why they would or would not participate in particular posts. These interview methodologies provide researchers more detail beyond what is available when content analysis is performed on archives of online interactions. The field of teacher learning in online spaces could easily employ these research methods to build a more robust understanding of interaction, or lack of interaction, patterns online. While interview studies can be resource consuming, they provide unique opportunities to learn how teachers make sense of learning opportunities and the interconnected nature of learning virtually and in F2F communities.

The findings also provide insight into lurking and brokering patterns of teachers and have implications for supporting mathematics teacher learning. Mathematics teacher educators and school- or district-level administrators should support a connection between virtual and F2F communities, as it is clear that knowledge is shared between both communities. While a majority of teachers still rarely participate in virtual learning spaces, this study illuminates the value of membership in the virtual space regardless of participation. More than half of the participants shared that they had integrated their professional learning into their personal usage of social media. Ms. Tracy exemplified this integration when she described why online learning was critical to her development:

> It's probably the biggest component of my professional learning because I find that 'm doing it all the time. Because it's interspersed in my personal feed on Facebook, it's just a part of my day. Often, the first thing that I'll see when I check my feed is something from a teacher group.

As teachers join virtual learning communities, they have the potential to gain access to more diverse ways of thinking about mathematics education. As teachers bring information from virtual learning to F2F settings, it is important to support the codification of these learning experiences by creating school-sponsored repositories of information obtained online. While some teacher leaders have already taken this upon themselves, these practices should be valued and supported by administrator investment, both through investing financially in the time to learn online and by providing the resources to support the repository.

In tandem with these recommendations, we echo a previous call from the field (Shapiro et al, 2019) by proposing the need for teacher training to support the curation of online resources. Mathematics teacher educators must provide training to preservice and in-service teachers to support their development of a critical lens to interrogate resources they come across in virtual learning communities. This need was made clear in our analysis of Ms. Longstrom's interaction within the FB group. During her artifact-stimulated recall, Ms. Longstrom shared her concern that members of the FB group were recommending strategies that misapplied growth mindset within mathematics classrooms. The ability to curate high-quality resources and critically analyze discussions is an important skill for teachers to have as they look for resources in virtual learning spaces.

Limitations and Conclusion

Based on the methods of recruitment and data collection, we note two limitations of this study. First, participants were selected through a process of convenience sampling and then a stratified sampling based on motivation to learn online. Because of this sampling method, and the disproportionate amount of White female teachers in the profession, all 18 interviewees self-identified as White and only one identifying as male. This factor is a major limitation of the study, as the voices of teachers that do not identify as White or male are missing from our data. This limitation could have been avoided, and most likely exchanged for a different limitation, if purposive sampling based on self-identified race would have

been employed based on motivation to learn online. In the future, we would like to develop a sampling strategy that is more inclusive of voices of teachers that do not identify as White. Such an approach would allow for a diversity of perspectives within the data.

The second limitation comes from the live look-in interview methodology. The live look-in is an underresearched method, and more research is needed to prove the effectiveness of this method. The live look-in could be perceived as performative and not authentic to how the teachers actually participate in the FB group. These limitations are offered to increase transparency in the research process while offering new directions in researching online teacher learning.

To conclude, the research presented in this paper is an attempt to push the field of mathematics teacher professional learning beyond the steady state (Slama et al., 2021, p. 6). Through providing detailed accounts of how teachers are connecting virtual and F2F communities to advance their learning, we highlighted evidence that supports a new direction in the field of teacher learning: teacher-led experiences. The categories presented provide a way to describe how teachers leverage learning within both virtual and F2F environments to meet their individual needs, or the needs of teachers they support, which is not necessarily the needs dictated by administrators or other personnel.

The categories may not apply to all teachers who seek to learn online; but rather, they are a starting point to help describe patterns in learning connections between virtual and F2F. We would be naive to assume the categories are complete. Thus, we hope the field of mathematics teacher learning will continue to investigate the connection between virtual and F2F communities, pushing for richer description and the ability to increase support of mathematics teachers and their professional learning.

References

Anderson, R. K., West, H., & Kates, A. (2022). Learning to subvert: How online learning communities can promote acts of creative insubordination. *Journal of Mathematics Teacher Education*. https://doi.org/10.1007/s10857-022-09543-6.

Amichai-Hamburger, Y., Gazit, T., Bar-Ilan, J., Perez, O., Aharony, N., Bronstein, J., & Dyne, T. S. (2016). Psychological factors behind the lack of participation in online discussions. *Computers in Human Behavior*, *55*, 268-277.

Ardichvili, A. (2008). Learning and knowledge sharing in virtual communities of practice: Motivators, barriers, and enablers. *Advances in Developing Human Resources, 10*(4), 541-554.

Bloom, B. S. (1953). Thought-process in lectures and discussions. *Journal of General Education*, *7*(3), 160–169.

Brandtzaeg, P. B., & Heim, J. (2011). A typology of social networking sites users. *International Journal of Web Based Communities*, *7*(1), 28-51.

Cansoy, R. (2017). Teachers' professional development: The case of WhatsApp. *Journal of Education and Learning*, *6*(4), 285-293.

Carpenter, J. P., & Krutka, D. G. (2015). Engagement through microblogging: Educator professional development via Twitter. *Professional Development in Education*, *41*(4), 707-728.

Carpenter, J. P., & Linton, J. N. (2018). Educators' perspectives on the impact of Edcamp unconference professional learning. *Teaching and Teacher Education*, *73*, 56-69.

Cranefield, J., Yoong, P., & Huff, S. L. (2015). Rethinking lurking: Invisible leading and following in a knowledge transfer ecosystem. *Journal of the Association for Information Systems, 16*(4), 3.

Creswell, J., & Poth, C. (2018). *Qualitative inquiry research design: Choosing among five approaches* (4th ed.). SAGE Publications.

Gurjar, N., & Sivo, S. (2022). Predicting and explaining pre-service teachers' social networking technology adoption. *Italian Journal of Educational Technology*, *30*(2). https://doi.org/10.17471/2499-4324/1245.

Gruzd, A., Paulin, D., & Haythornthwaite, C. (2016). Analyzing social media and learning through content and social network analysis: A faceted methodological approach. *Journal of Learning Analytics*, *3*(3), 46-71.

Hu, S., Torphy, K. T., Opperman, A., Jansen, K., & Lo, Y. J. (2018). What do teachers share within socialized knowledge communities: A case of Pinterest. *Journal of Professional Capital and Community, 3*(2), 97-122.

Kahnwald, N., & Köhler, T. (2006). Microlearning in virtual communities of practice? An explorative analysis of changing information behaviour. In T. Hug, M. Lindner, & P. A. Bruck (Eds.), *Micromedia & e-Learning 2.0: Gaining the Big Picture. Proceedings of Microlearning Conference 2006* (pp. 157–172). MicroLearning Blog.

Kelly, N., & Antonio, A. (2016). Teacher peer support in social network sites. *Teaching and Teacher Education*, *56*, 138-149.

Kent, C., Rechavi, A., & Rafaeli, S. (2019). The relationship between offline social capital and online learning interactions. *International Journal of Communication*, *13*(26). 1186–1211

Kollock, P., & Smith, M. (1996). Managing the virtual commons. IN S. C. Herring (Ed.), *Computer-mediated communication: Linguistic, social, and cross-cultural perspectives* (pp. 109-128) John Benjamins.

Kumar, J. (2019). How psychological ownership stimulates participation in online brand communities? The moderating role of member type. *Journal of Business Research*, *105*, 243-257.

Larsen, J., & Parrish, C. W. (2019). Community building in the MTBoS: Mathematics educators establishing value in resources exchanged in an online practitioner community. *Educational Media International*, *56*(4), 313–327. https://doi.org/10.1080/09523987.2019.1681105.

Li, S., Zheng, J., & Zheng, Y. (2020). Towards a new approach to managing teacher online learning: Learning communities as activity systems. *The Social Science Journal, 58*(3), 383-395.

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.

Liljekvist, Y., van Bommel, J., & Olin-Scheller, C. (2017). Professional learning communities in a web 2.0 world: Rethinking the conditions for professional development. In I. H. Amzat & N. P. Valdez (Eds.), *Teacher empowerment toward professional development and practices: Perspectives across borders* (pp. 269–280). Springer.

Lundin, M., Lantz-Andersson, A., & Hillman, T. (2020). Teachers' identity work in a professional facebook group. *Journal of Information Technology Education*, *19*, 205-222

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.

Macià, M., & García, I. (2018). Professional development of teachers acting as bridges in online social networks. *Research in Learning Technology*, *26*, 1-20.

Mansour, A. (2020). Shared information practices on Facebook: The formation and development of a sustainable online community. *Journal of Documentation*, *76*(3), 625-646

Marett, K., & Joshi, K. D. (2009). The decision to share information and rumors: Examining the role of motivation in an online discussion forum. *Communications of the Association for Information Systems, 24*(1), 4.

Nielsen, J. (2006). *Participation inequality: Lurkers vs. contributors in Internet communities*. http://www.nngroup.com/articles/participation-inequality/

Nguyen, T. M. (2020). Four-dimensional model: a literature review on reasons behind lurking behavior. *VINE Journal of Information and Knowledge Management Systems, 51*(2), 302-317.

Parrish, C. (2016). *Supporting the development of teachers' attributes needed for the selection and implementation of cognitively demanding tasks through engagement with the math-Twitterblogosphere* [Doctoral

dissertation, Auburn University]. http://etd.auburn.edu/handle/10415/5330.

Parrish, C. (2017). Informal mentoring within an online community. In A. M. Kent & A. M. Green (Eds.), *Across the domains: Examining best practices in mentoring public school educators throughout the professional journey* (pp. 113–131). Information Age Publishing.

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: An International Journal of Research and Studies*, *82*(1), 33-42.

Preece, J., Nonnecke, B., & Andrews, D. (2004). The top five reasons for lurking: improving community experiences for everyone. *Computers in Human Behavior, 20*(2), 201-223.

Qian, Y., Hambrusch, S., Yadav, A., & Gretter, S. (2018). Who needs what: Recommendations for designing effective online professional development for computer science teachers. *Journal of Research on Technology in Education*, *50*(2), 164-181.

Risser, H., & Bottoms, S. (2018). Becoming the MTBoS: Predicting sense of belonging for a grassroots blogging network. *International Journal of Web Based Communities, 14*(1), 21–37.

Robson, J. (2018). Performance, structure and ideal identity: Reconceptualising teachers' engagement in online social spaces. *British Journal of Educational Technology*, *49*(3), 439-450.

Shafie, L. A., Yaacob, A., & Singh, P. K. K. (2016). Lurking and L2 learners on a Facebook group: The voices of the invisibles. *English Language Teaching, 9*(2), 1–12. https://doi.org/10.5539/elt.v9n2p1.

Shapiro, E. J., Sawyer, A. G., Dick, L. K., & Wismer, T. (2019). Just what online resources are elementary mathematics teachers using? *Contemporary Issues in Technology and Teacher Education*, *19*(4), 760–686. https://citejournal.org/volume-19/issue-4-19/mathematics/just-what-online-resources-are-elementary-mathematics-teachers-using

Schlager, M. S., Farooq, U., Fusco, J., Schank, P., & Dwyer, N. (2009). Analyzing online teacher networks: Cyber networks require cyber research tools. *Journal of Teacher Education*, *60*(1), 86-100.

Slama, R., Moussapour, R., Benoit, G., Anderson, N., & Reich, J. (2021, October 13). *The future of math teacher professional learning*. MIT Teaching Systems Lab. http://edarxiv.org/kncs9

Tour, E. (2017). Teachers' self-initiated professional learning through personal learning networks. *Technology, Pedagogy and Education*, *26*(2), 179-192.

Trust, T. (2016). New model of teacher learning in an online network. *Journal of Research on Technology in Education*, *48*(4), 290-305.

Trust, T. (2017). Motivation, empowerment, and innovation: Teachers' beliefs about how participating in the Edmodo math subject community shapes teaching and learning. *Journal of Research on Technology in Education*, *49*(1-2), 16-30.

Trust, T., Carpenter, J. P., & Krutka, D. G. (2018). Leading by learning: Exploring the professional learning networks of instructional leaders. *Educational Media International, 55*(2), 137-152.

Tsiotakis, P., & Jimoyiannis, A. (2016). Critical factors towards analysing teachers' presence in on-line learning communities. *The Internet and Higher Education*, *28*, 45-58.

van Bommel, J., Randahl, A. C., Liljekvist, Y., & Ruthven, K. (2020). Tracing teachers' transformation of knowledge in social media. *Teaching and Teacher Education*, *87*, 102958.

Watkins, K. E., & Marsick V. J. (1992). Towards a theory of informal and incidental learning in organizations. *International Journal of Lifelong Education 11 (4),* 287–300.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge University Press.