Enriching TPACK in mathematics education: using digital interactive notebooks in synchronous online learning environments

Terrie McLaughlin Galanti
Department of Teaching, Learning, and Curriculum, University of North Florida, Jacksonville, Florida, USA, and
Courtney Katharine Baker, Kimberly Morrow-Leong and Tammy Kraft
Mathematics Education Leadership, George Mason University, Fairfax, Virginia, USA

Abstract
Purpose – In spring 2020, educators throughout the world abruptly shifted to emergency remote teaching in response to an emerging pandemic. The instructors of a graduate-level synchronous online geometry and measurement course for practicing school teachers redesigned their summative assessments. Their goals were to reduce outside-of-class work and to model the integration of content, pedagogy and technology. This paper aims to describe the development of a digital interactive notebook (dINB) assignment using online presentation software, dynamic geometry tools and mathematical learning trajectories. Broader implications for dINBs as assessments in effective distance learning are presented.

Design/methodology/approach – The qualitative analysis in this study consists of a sequence of first-cycle coding of mid-semester surveys and second-cycle thematic categorizations of mid-semester surveys and end-of-course reflections. Descriptive categorization counts along with select quotations from open-ended participant responses provided a window on evolving participant experiences with the dINB across the course.

Findings – Modifications to the dINB design based on teacher mid-semester feedback created a flexible assessment tool aligned with the technological pedagogical content knowledge (TPACK) framework. The teachers also constructed their own visions for adapting the dINB for student-centered instructional technology integration in their own virtual classrooms.

Originality/value – The development of the dINB enriched the TPACK understandings of the instructors in this study. It also positioned teachers to facilitate innovative synchronous and blended learning in their own school communities. Further analysis of dINB artifacts in future studies will test the hypothesis that practicing teachers’ experiences as learners increased their TPACK knowledge.

Keywords Research, Mathematics, Distance learning, Higher education, Teaching methods, Assessment and e-assessment

Paper type Research paper

Introduction
School teachers and teacher educators were forced to transition from face-to-face instruction to emergency remote learning (Milman, 2020) in spring 2020 in response to the COVID-19 pandemic. Yet, careful instructional design and development, which
recognizes learning as both a social and cognitive process” (Hodges et al., 2020) can be the missing piece of emergency remote teaching. As schools and universities throughout the world face continuing instability in their efforts to return to face-to-face instruction, there remains a critical need to replace this temporary and reactionary model of instruction with effective and sustainable distance teaching. While emergency remote teaching spawned a plethora of pedagogical innovations (Ferdig et al., 2020) to support teacher educators, there remains a specific need to design synchronous distance learning experiences with a purposeful emphasis on assessing student understanding. These assessments should reflect evidence-based knowledge of integrated content, pedagogy and technology.

This research study describes the instructional design decisions of four mathematics teacher educators during their synchronous online graduate-level geometry and measurement content courses in summer 2020. These courses are designed to deepen both content and pedagogical content knowledge (PCK) (Shulman, 1986) for practicing primary and secondary school teachers. In this paper, university faculty and doctoral students are “instructors,” students in the graduate level content course are “teachers” and primary and secondary school learners are “students”.

Even though this course has been delivered yearly since 2015 in a fully synchronous online format, we decided to redesign performance-based assessments (PBAs) to respond with care (Owens and Ennis, 2005; Walker and Gleaves, 2016) in light of the pandemic challenges (Ravitch, 2020). The redesigned assessments were theorized to acknowledge the unique stresses of the pandemic, maintain the rigor of the geometry and measurement content, and provide transferrable assessment ideas that teachers could adapt in their own virtual classrooms. Study findings have implications for designing robust and equitable online teaching experiences, which encourage collaborative problem-solving, make learning visible in real-time, provide authentic feedback, and hold students accountable for developing content knowledge.

Theoretical background

The effective use of technology for online teaching transcends the knowledge of the functionality of the tools. Teacher education programs should embed technology in content-specific and methods courses (Hersh, 2013; Martin, 2015) to inspire student creativity. While technological innovations offer new potential for classroom inquiry, collaboration and problem-solving, Culp et al. (2005) found that teachers tend to prefer technology that improves their existing practices. Despite increasing access to innovative technology, practicing teachers continue to enact largely teacher-centric instruction (Kopcha et al., 2020). In the unique context of the COVID-19 pandemic, teachers must creatively draw upon discipline-based content knowledge, pedagogical experience and emerging technologies as they navigate synchronous video conferencing platforms. This specialized knowledge can be broadly described as technological pedagogical content knowledge or TPACK, which:

[...] allows teachers, researchers, and teacher educators to move beyond oversimplified approaches that treat technology as an ‘add-on’ instead to focus again, and in a more ecological way, upon the connections among technology, content, and pedagogy as they play out in classroom contexts (Mishra and Koehler, 2006, p. 67)

Within the TPACK framework, these three knowledge domains intersect to yield three new integrative domains of knowledge, namely, PCK, technological content knowledge (TCK) and technological pedagogical knowledge (TPK).
Teacher educators must integrate PCK, TCK and TPK in both formal post-secondary education programs and in informal professional development settings. Niess (2005), drawing upon Borko and Putnam (1996), proposed four components of building technological PCK (Shulman, 1986) in science and mathematics teacher education programs:

- An overarching understanding of teaching a particular subject using technology to facilitate student learning.
- Knowledge of instructional strategies and representations for teaching a particular topic through the use of technology.
- Knowledge of students’ misconceptions, understandings, thinking and learning in a particular subject matter and how these might be represented using technology.
- Knowledge of curriculum materials that implement technology to enhance learning in a given content area.

More recently, Harrington (2016) and colleagues reviewed the literature in mathematics teacher education using the lens of these four components of TPACK. They reported a lack of evidence of TPACK development for teachers in the primary grades and argued for more research on teachers’ experiences with learning mathematics through multiple technologies. Recent research on primary teachers’ enactment of TPACK in the classroom (Loong and Herbert, 2018; Urbina and Polly, 2017) confirms that teachers need additional experiences using technology as learners to realize its potential in redesigning mathematical tasks for their students. In addition, much of the extant research on teachers’ use of TPACK has not been subject-specific (Akyuz, 2018) and relies on self-assessment instead of PBA. This need for additional research on the assessment of teachers’ use of technology for learning mathematics, coupled with our obligation to prepare practicing teachers amidst a sudden move to online learning, motivated the design and implementation of this study.

We have used our TPACK understandings in our facilitation of multiple synchronous online mathematics teacher leadership courses from a social constructivist perspective. These courses focused on the integration of content and pedagogy while leveraging the technological capacity to build more authentic engagement opportunities than may have been possible in face-to-face classrooms (Baker et al., 2019, Baker and Hjalmarson, 2019). However, there had not been an expectation the teachers would, in turn, need to facilitate mathematics learning in their own wholly synchronous online primary and secondary classrooms. In response to the pandemic, we theorized that a redesign of our traditional Council for Accreditation of Educator Preparation PBAs could both reduce the outside-of-class work expectations and align more purposefully with geometry and measurement teaching and learning. Furthermore, these redesigned PBAs could become relevant models for online formative and summative assessments in schools by engaging teachers in the integration of TPACK domains. Thus, the graduate course would not only better support the teachers as mathematics learners, but it could also inspire creative student-centered teaching and assessment in their own online classrooms.

The following research questions guided this study:

**RQ1.** How do mathematics teacher educators redesign PBAs for practicing teachers in a synchronous online mathematics specialist geometry and measurement course to respond to the challenges of COVID-19?
**Methodology**

**Context of study**

The four university course instructors met bi-weekly beginning in May 2020 to collaboratively plan three sections of an eight-week summer session masters-level geometry and measurement content course. The participants \((n = 45)\) were classroom teachers, coaches and specialists from multiple K-12 school divisions across one mid-Atlantic state in the USA. The teachers who had transitioned to emergency remote teaching in March 2020 were still working with their primary and secondary students during the first three weeks of the graduate course. Their emergency remote teaching models varied from fully asynchronous to blended online instruction. At the university, the teachers were enrolled in either a mathematics specialist certification program or in a curriculum and instruction degree program. Six teachers were new to the graduate program; the remaining teachers had previously completed at least one semester of synchronous online learning within the graduate program.

With the persistence of COVID-19 infections during the late spring, the instructors anticipated that teachers would need to shift from emergency remote teaching to more intentional digital learning for the upcoming school year. In prior offerings of this content course, the PBAs were four reflective papers written after collaborative experiences with rich mathematical tasks. These papers were summative assessments of content, pedagogical and technological knowledge in relation to the five mathematical process standards (National Council of Teachers of Mathematics [NCTM], 2000). For the summer 2020 course, the instructors redesigned the PBAs to integrate real-time collaborative content experiences and to align with research on geometry and measurement learning trajectories (Battista, 2006; Howse and Howse, 2014; Sarama and Clements, 2003; van Hiele, 1984). These design decisions were intended to increase the cognitive demand of content experiences for teachers with specific attention to how students develop geometry and measurement knowledge. The changes were also designed to integrate teachers’ extant PCK by situating effective mathematics teaching practices (National Council of Teachers of Mathematics [NCTM], 2014) within novel technology applications and platforms.

The instructors had previous experience with facilitating synchronous online geometry and measurement courses for teachers using real-time collaborative problem-solving with Google slides and Blackboard Collaborate Ultra breakout rooms (Baker and Hjalmarson, 2019). In the summer 2020 course, teachers engaged in similar collaborative problem-solving but were expected instead to use digital tools (e.g. GeoGebra) to capture their problem-solving processes during each synchronous class session. Each teacher maintained an editable record of content experiences using instructor-provided digital interactive notebook (dINB) templates. Interactive notebooks have been widely used in face-to-face school classrooms as a metacognitive inquiry tool through which students engage in sensemaking and creatively represent their thinking (Chesbro, 2006; Mallozzi and Heilbronnner, 2013; Waldman and Crippen, 2009). Interactive notebooks also empower teachers with assessment flexibility ranging from formative check-ins to summative evaluations. Consistent with this use, the dINBs in this course were used formatively, and they were submitted as two of four required PBAs for the teachers’ digital portfolios.

The instructor design decisions and the teacher’s actions in creating the dINB as a redesigned summative assessment are synthesized in a methodology flowchart (Figure 1). The dINB slides for this geometry and measurement course were specifically designed to
capture in-class collective content synthesis and individual reflection. They also offered a care-inspired (Walker and Gleaves, 2016) reduction in the outside-of-class work expectations. In lieu of synchronous meetings for Classes 8 and 13, teachers were offered asynchronous work sessions to review and prepare their dINB slides to meet course PBA requirements. At these times, instructor feedback was provided for teachers to reflect on and then revise their dINBs to demonstrate mastery of course content and pedagogical standards (National Council of Teachers of Mathematics [NCTM], 2012). The instructors also explicitly shared the following goals for the PBA redesign with teachers:

- Demonstrate an ethic of care and understanding of the stresses faced during the pandemic.
- Increase the relevance of course work by providing a new form of assessment (dINB) that might be integrated into their school teaching practice.
- Align in-class dINB expectations to PBA evaluation criteria to minimize time spent outside of class.

In sharing these goals with the teachers, the instructors created an important transparency in this qualitative study. In their roles as both instructors and researchers, the authors were committed to a co-production of knowledge (Yin, 2016) with their teachers to better understand how revised assessments using a TPACK framework could respond to the pandemic and inform future online mathematics teaching.

**Data collection**

Teacher responses to a mid-semester survey (after Class 7) and reflective prompts during the final synchronous session (Class 15) were collected for analysis. The mid-semester surveys were conducted anonymously and consisted of three open-ended questions.

**Q1.** What aspects of the dINB are most useful to you?

**Q2.** What aspects of the dINB are most challenging to you?

**Q3.** Do you have any suggestions for the next dINB?

The aim of these questions was to gain feedback on teachers’ use and perception of the dINB as learners during the first half of the graduate course.

The two reflective prompts during the final synchronous class elicited teachers’ perspectives of the dINB from multiple perspectives. The first prompt asked teachers to...
reflect on the dINB as learners and both identify aspects of the dINB that were useful and helped them to make sense of the course content. The second prompt asked teachers to reflect on the dINB as facilitators of future virtual instruction and share how, if at all, the dINB might be implemented in school classrooms. These prompts were posted on multiple Google slides and individual text boxes were provided for teachers to record their thinking. Teachers were asked to attach their names to provide ownership to their ideas and make their thinking public to their classmates. An additional artifact gathered during the final class was the chatbox dialogue from one class. During the 10 minutes provided to teachers to respond to the prompts, several teachers began reading and then commenting on their peers’ thinking in the chatbox of Blackboard Collaborate Ultra. This dialogue was occurring in parallel with teachers’ individual responses to the two reflective prompts, and it represents a collective thinking of multiple students.

**Data analysis**

Responses from participants across all three courses were compiled and qualitatively analyzed. A first cycle In Vivo coding (Saldaña, 2016) scheme was used first on the anonymous mid-semester survey, and afterward on the reflective prompt responses to capture and honor the specific language of the participants (e.g. *summarize learning, processing individually, make it our own and keep track of thinking*). The coding order of surveys first and prompt responses second was intentional to capture changes over time between the data sources (Maxwell, 2005). Participants’ connected codes were then placed in categories (e.g. *reflection, synthesizing content, dINB structural formatting and dINB organization*) and the reduction of these categories led to the emergence of a few prominent themes (Maxwell, 2005). Within each theme, frequencies of codes and categories were then quantified. Data sources were organized in a matrix (Merriam, 2009), and analysis focused on expressed changes from teachers’ mid-semester surveys to final reflections on online distance learning. The resulting codes and categories represent their perspectives as learners in a graduate geometry and measurement course and as teachers who could use dINBs in their own virtual classrooms. Although the dINBs were not coded, the teachers’ representations of content, pedagogical and technological knowledge in their Google Slides were used to triangulate evidence from the surveys and prompt responses.

**Findings**

Our efforts to meet the challenges of the COVID-19 pandemic for teachers who were still engaged in emergency remote teaching created a unique opportunity to consider new ideas for building their geometry and measurement content knowledge, even under uncertain circumstances. The dINB was initially conceptualized as a redesign that would streamline the summative assessment workload and model formative assessment strategies for school classrooms. More importantly, the dINB, became evidence of the instructors’ initial attention to the three TPACK knowledge domains and the emergence of rich intersectionality across the domains (Figure 2).

*The digital interactive notebook at the center of the technological pedagogical content knowledge framework*

The TPACK framework acknowledges a “dynamic, transactional relationship between all three components” (Koehler and Mishra, 2005), and the knowledge intersections within TPACK became increasingly explicit throughout the course. The transactions appeared in the form of our initial dINB design decisions, within the synchronous group discourse, and
in the teachers’ individual reflective work outside of class. Teachers constructed content understandings while working in small groups using instructor-provided Google Slides templates. Simultaneous editing within the Google Slides ecosystem enabled the instructors to design slide templates that were uniform and customizable. More importantly, the dynamic nature of the document also allowed individual students’ notebooks to become the locus of outside-of-class instructor feedback. This affordance was only possible because of the modality of Google Slides within a digital class folder; teachers did not need to submit an assignment to receive feedback. This feedback enabled individuals to reflect on and synthesize their learning prior to formal PBA submissions. Taken together, the dINB slides integrated content, pedagogy and technology to conduct formative assessment with targeted intentionality, both during class and at strategic points throughout the semester.

**Technological pedagogical knowledge**
The dINB relied on the use of Blackboard Collaborate Ultra as a synchronous learning platform with breakout rooms for small-group collaboration through interactive Google Slides. As instructors, we could, simultaneously monitor the visual emergence of each group’s thinking and virtually enter breakout rooms to prompt or question as appropriate. During each class, the teachers engaged in problem-solving as they created and connected multiple representations of their geometric thinking. The real-time display of collaborative work supported the instructor in immediate evaluation and modification of planned activities to meet teachers’ learning needs. As the teachers copied and created their own Google Slides for their dINBs at the end of each class session, the slides became a virtual, editable record of in-class collaboration and debrief, with an outside-of-class opportunity for revision and reflection at the discretion of the individual teacher.

**Technological content knowledge**
We created several dINB activities, which encouraged the use of GeoGebra, a dynamic geometry software tool. The teachers’ growing proficiency with GeoGebra allowed them to advance their static conceptualizations of geometry content. Teachers had opportunities to
reflect on their own content understandings within the van Hiele hierarchy of levels of geometric thought (Howse and Howse, 2014; van Hiele, 1984) with a goal of moving their own thinking toward generalization and proof.

In the task associated with the exemplar dINB slide in Figure 3, teachers used GeoGebra to create nine examples of a triangle that matched the properties at the intersection of each row and column. This task structure gave small groups of teachers the opportunity to deepen their knowledge of classifications of angles and sides and to recognize that some triangle property pairs were not possible. The dynamic nature of GeoGebra allowed for the rapid creation of multiple triangles. Examination of changing side and angle relationships revealed the inconsistencies, which make two of the property combinations impossible to construct. This teacher was also able to justify her reasoning and connect her work retrospectively to her own geometry learning trajectory.

**Pedagogical content knowledge**

The dINB slides documented effective mathematics teaching and learning practices (National Council of Teachers of Mathematics [NCTM], 2014) with a specific focus on conceptual understanding. The selection of tasks with high cognitive demand (Smith and Stein, 1998) and prompts to connect concrete, pictorial and abstract representations (Lesh et al., 1987) revealed student thinking. Additionally, we developed INB templates, which challenged teachers to use course case study readings (Schifter et al., 2017a, 2017b) to situate students’ actions, drawings or gestures along the van Hiele hierarchy of levels of geometric thought. Teachers’ pedagogical expertise in developmental levels of geometric reasoning (Van de Walle et al., 2018) positions them to design instruction that meets students at their individual levels of understanding and moves them toward more mature levels of understanding. The dynamic nature of Google Slides, paired with synchronous communication in Blackboard Collaborate Ultra, facilitated easy conversation as teachers collaboratively recorded their observations of the student actions and engaged in real-time editing with their colleagues. Unlike traditional chart paper artifacts, the dINB slides are accessible and editable later.

The instructors’ early decision to add GeoGebra as content-specific technology was intended to offer opportunities for teachers not only to learn a useful digital tool for use in their own classrooms but also to give them space to learn geometry in depth. The addition of

![Figure 3. Example of use of GeoGebra to build PCK at the abstraction level of the van Hiele (1984) learning trajectory](image)
analysis of student work using learning trajectories began as a strategy for developing teachers’ PCK. An interesting byproduct of the integration of GeoGebra technology and the van Hiele levels of geometric thought was the opportunity for participants to use the dynamic nature of GeoGebra to explore concepts and analyze their own geometric thinking with greater fidelity. They better understood the movement from informal to formal deductive reasoning as they used the tools of GeoGebra to cultivate more rigorous geometric thinking. Because the redesign of the PBAs integrated the dynamic geometry learning environment, teachers had more opportunities to focus on the growth of their own content knowledge. They reflected on their own learning trajectories within the developmental levels of geometric thinking in addition to their PCK for teaching with technology.

**Teachers as distance learners in a synchronous online geometry and measurement course**

Analysis of both anonymous mid-semester survey data about the usefulness of the dINB from a learner perspective and the end-of-course collaborative responses about the usefulness of the dINB from a teaching perspective provided evidence that the dINB both responded to COVID-19 challenges and created new learning and teaching opportunities that could extend to school settings. The teachers connected both perspectives as they described future formative assessment plans for their own primary and secondary distance learning environments.

In their mid-semester survey responses about the usefulness and challenges of the dINB, over half of teachers (55%) acknowledged the pivotal role it played in organizing, reflecting on and synthesizing the mathematical content knowledge presented. Although some teachers noted that revisiting the slides in the days following class times was challenging because they were not able to recall all of the details they needed to revise their slides, a greater proportion appreciated the opportunity to revisit content because it allowed them to dig deeper or make additional connections. Figure 4 is an exemplar of one teacher’s individual problem-solving slide on measurement from synchronous Class 9 and her modifications for her dINB. Her “note to self” on the initial slide is expanded and developed into the work shown on the final slide.

Using the INB as a reference after class – there were many times I was able to dig deeper into concepts from class that I may not have had time to process.

Going back after class and cleaning up the slides and putting them in my own notebook allows me time to reflect on the concepts of the class and try to mentally organize them into a personal coherent whole.

In previous online mathematics content courses, teachers had engaged in collaborative problem-solving and had represented their ideas in free form with text and uploaded photos on group Google Slides. In the first five classes of the redesigned geometry and measurement course, the template for group work was also the template for the individual INB. The questions and workspace on the slides structured their responses in ways that held them accountable for demonstrating mastery of targeted concepts. The mid-semester feedback communicated the importance that dINB ownership and choice held for the teachers. One of the greatest challenges teachers experienced with the dINB was grounded in either template formatting (38% of teachers) or in the digital organization of the slides. Teachers desired increased autonomy of formatting to ease their use of the dINB and were frustrated by static components of the original dINB templates. Specific requests included the ability to change existing backgrounds, textboxes, tables and links. Although not directly connected to the dINB design, 21% of
teachers expressed the desire for additional time to process and organize the mathematical content representations. Figure 5 is an exemplar of another teacher’s revision of her group’s problem-solving slide for her dINB.

At the end of class it’s hard for me to go back and clean up the slides or add more details. I need to find a time the following day after class that I can take some time to get caught up on my slides, so I don’t fall behind.

With the exercise of pedagogic care (Walker and Gleaves, 2016), we had initially created pre-formatted dINB templates. The mid-semester survey responses revealed that this design decision had limited teachers’ choice and ownership in their dINBs. Based on this mid-semester feedback, we revised the templates to include additional information such as class session number and activity name. All textboxes, images and backgrounds were editable to provide the teachers with choice in how they displayed their thinking. Teachers also learned to link from one slide to another and they used this skill to create a dynamic table of contents. To address teacher concerns with pacing and content, we decreased the number of dINB activities presented in each class, created slides that shared each day’s guiding ideas and explicitly highlighted the central mathematical topics of each class session. These
changes ensured that the instructional goals of each session were communicated clearly and provided ample time for reflection. Verbal feedback in subsequent classes provided evidence these design adaptations to meet teacher needs were appreciated and valued.

In the final class sessions, teachers were asked to elaborate on their mid-semester survey responses for the second iteration of the dINB design. Most notably, 74% of teachers acknowledged the way in which the dINB served as a collaborative structure to learn the mathematical content from multiple perspectives with an emergent connection to their own classroom teaching.

The dINB provided me with a space to revisit and reflect on our learning throughout the course. I believe that reflection is one of the most important practices as a learner and educator. As crucial as it is to reflect on learning, it can sometimes be difficult to find the time and the dINB helped make the time.

I think the dINB pushed me to reflect on the lessons from each day. In order to make full sense of each lesson and consider how I would apply it, I needed to go back, review, reflect, and plan next steps. While the reflections felt challenging, they really forced me to connect the lesson to my own practice.

*Teachers as emerging leaders in primary and secondary distance learning*

Despite the challenges the teachers expressed with dINB structures in the early part of the course, instructor conversations about the dINB as a potential structure for school settings
yielded explicit connections between the teachers’ own learning experiences and richer TPACK understandings, which could ultimately support their school communities. “Having templates aligned with rich tasks, proofs and major concepts is very helpful and maintains the practice of aligning everything to [content standards].” During the mid-semester survey, 16% of teachers had expressed unsolicited enthusiasm about implementing dINBs in anticipated return to virtual school in fall 2020, and five teachers had already implemented dINBs within their school settings. These teachers described their introduction of dINBs to grade-level teams across all subjects and their use of dINBs to promote fact fluency in mathematics during summer school. Another teacher shared that she was “researching how to implement a dINB in my classroom with my instructional technology coach to present to other seventh grade teachers.”

The remaining teachers had not yet made specific use of dINB structures but shared their ideas for the potential value of this tool. Several teachers envisioned opportunities for students to engage with content and technology in meaningful ways that sustained their pedagogical commitments to student-centered classrooms.

Students can use this tool to review any material that we discussed in class. Multiple exposures to the same content can help them master the skills they need to be successful in the curriculum. It is a great way for them to collaborate with peers in a logical format that they can all benefit from in breakout groups during class.

During the final synchronous class, teachers expressed specific ways in which they planned to integrate the dINB into their own virtual teaching in the fall. Several described their use of a paper-based INB prior to the pandemic and offered a new understanding about integrating a face-to-face assessment practice with virtual teaching at both the classroom and school level. Additionally, many teachers envisioned dINBs for both summative and formative assessment.

This is a chance to formatively assess student thinking, and to hold students accountable for their own learning, even when a class is driven by group work. It’s a great way to encourage self-reflection in students, as they can clearly see the ways they have grown through the notebook entries.

I like the idea of using dINBs during each unit. It can be a summative assessment at the end of the unit, kind of like a portfolio. This is definitely something that I plan on using with my students.

I think it allows the instructor to really see where students are at in their learning journey. As an instructor, you may hear things in a breakout room or whole class discussion, but this allows you to directly comment/observe on their individual learning. I plan to implement this somehow using Canvas.

Further evidence of the teachers’ evolving thinking as they considered the potential affordances of the dINB in virtual school classrooms is presented in Table 1. The conversation from the Blackboard Collaborate Ultra chatbox captures the ways in which teachers’ dINB experiences as learners illuminate opportunities to innovate their teaching at the intersection of content, pedagogy and technology.

Discussion and implications
Unlike many other teacher educators who were faced with a rapid and unanticipated shift from face-to-face to online instruction in spring 2020 due to COVID-19, we were able to respond to these unique circumstances by reflecting on our prior iterations of a synchronous online geometry and measurement course. We recognized the multifaceted challenges that the shift to emergency remote teaching had created for our teachers as both graduate students and as future facilitators of online learning in their
own school contexts. Our actions to show care by modifying the outside-of-class expectations became a productive model of TPACK integration for meaningful formative and summative assessment. Analysis of teacher experiences with the dINB from both learning and teaching perspectives affirmed the dualized goals that we as instructors had set for our course redesign. The dINB sits at the center of the TPACK framework not only as a product of our design decisions but also as a reflective framework for student-centered instructional technology integration.

The dINB design and implementation as a PBA for this content course represents our attentiveness to each of the components of technological PCK (Niess, 2005) in mathematics education. Teachers integrated dynamic geometry content tools in their own problem-solving, synthesized multiple technology tool representations using the creative potential of Google Slides and analyzed ways in which these types of technology could encourage students to advance along their learning trajectories. The findings of this study contribute to the empirical understandings of TPACK as a productive framework for integrating technology that supports flexible reflection on ideas and the advancement of content understandings.

The findings of this study also begin to fill gaps in research on the assessment of teacher’s use of technology for mathematics learning (Akyuz, 2018; Harrington et al., 2016). While the data analysis for this study did not focus on individual student dINB submissions, we recognize the exciting potential for future research to connect teachers’ experiences as mathematics learners to the development of TPACK and its transfer to their practice. The

---

### Table 1.
Partial Transcript of Chat Box from Slide-based Survey during the Final Class

<table>
<thead>
<tr>
<th>Chatbox Dialogue</th>
<th>Timestamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Farah) The dINB can serve many learning styles as the digital INB allows for multiple representations and creativity</td>
<td>4.48pm</td>
</tr>
<tr>
<td>(Lissa) I LOVE the idea about sharing with parents and inviting them to see (and even be a part of) the collaboration happening with virtual learning! I think maybe for younger students you could have the majority of it filled out and have it be more teacher directed/whole group. Then students could maybe add a reflection using sentence frames</td>
<td>4.49 pm</td>
</tr>
<tr>
<td>(Robin) This took a lot of self-motivation to stay engaged and with it throughout our course</td>
<td></td>
</tr>
<tr>
<td>(Nicole) Typing is challenging for 1st graders- if you use something like Seesaw they can record their voice</td>
<td></td>
</tr>
<tr>
<td>(Robin) I'm thinking that too, Farah. And journal prompts already inputted... or the possibility of recording their thinking with their voice...</td>
<td></td>
</tr>
<tr>
<td>(Nora) That's a good idea Farah, sentence frames are really helpful for English Language Learners (ELL) too</td>
<td></td>
</tr>
<tr>
<td>(Lissa) Yes Nora – thinking about ELLs as well</td>
<td></td>
</tr>
<tr>
<td>(Adrianne) Yes, I also like the idea of engaging families via the INB!</td>
<td></td>
</tr>
<tr>
<td>(Olivia) I was thinking this as well and as the year progresses we can start to remove some of those frames</td>
<td></td>
</tr>
<tr>
<td>(Lissa) Also these editable templates could be really helpful</td>
<td></td>
</tr>
<tr>
<td>(Olivia) Nicole, the voice recording feature would be a great tool for them to use in place of typing</td>
<td></td>
</tr>
<tr>
<td>(Lissa) Then the frames are there but they can remove or add on as they are ready</td>
<td></td>
</tr>
<tr>
<td>(Farah) Yeah I think it would just be one of those trial and error things to see what works and doesn’t. Also you can get feedback from the students to see how it's going and what could change.</td>
<td></td>
</tr>
</tbody>
</table>
dINB may also become a model for online collaboration, curriculum and assessment design across all school disciplines.

Conclusion: challenges and opportunities of teaching and learning in COVID-19

COVID-19 presented multiple challenges for us as teacher educators at the beginning of the summer 2020 semester. We needed to recognize the extraordinary circumstances that our teachers were living as they balanced the disruption of their personal and professional lives. To meet the needs of our teachers, we also needed to streamline course requirements by increasing the relevance and authenticity of their PBAs. However, perhaps, more importantly, the increasing likelihood that teachers would return to online instruction in the fall challenged us to design lessons and assessments that could grow teachers’ capacity across the TPACK framework. We embraced these challenges as a set of opportunities to develop teachers’ knowledge of effective online mathematics instruction and to extend previous research studies on TPACK. Thus, COVID-19 has created not only an opportunity but also an obligation to develop TPACK in primary and secondary teachers. Although it is beyond the scope of this study to offer specific evidence of increased TPACK knowledge in our teachers, the purposeful course redesign to more deeply integrate TCK, PCK and TPK enriched our own scholarship as teacher educators. It also positioned our teachers to facilitate innovative distance learning in their own school communities.

In their recent review of TPACK literature, Saubern et al. (2020) advocated for a shift in focus from the structure of the TPACK diagram to the development and measurement of this knowledge in teacher education. We hypothesize that our use of TPACK in the design and implementation of the dINB is a model for developing teachers’ knowledge of effective use of technology. There is a growing need to connect evidence of teachers’ use of technology as mathematics learners with a meaningful improvement of content instruction through technology (Niess and Gillow-Wiles, 2017) in primary and secondary teaching. The global transition to online and blended learning models necessitated by COVID-19 may present new opportunities to shift educational practice beyond the pandemic (Li and Lalani, 2020). The dINB as a summative assessment in teacher education addresses the challenges of engaging students in online mathematics learning and creates new opportunities for formative assessment in online teaching. The development and application of TPACK can increase students’ access to meaningful content experiences in synchronous online learning environments. Teacher educators have a unique opportunity in this pandemic and beyond to foster both teacher expertize and situated leadership in high-quality distance education. As such, post-secondary courses and professional development offerings should model the thoughtful content-driven integration of technology, pedagogy and assessment design.

References


National Council of Teachers of Mathematics (NCTM) (2014), Principles to Actions: Ensuring Mathematical Success for All, Author, Reston, VA.


Further reading

Corresponding author
Terrie McLaughlin Galanti can be contacted at: terrie.galanti@unf.edu