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Using an Enhanced Video-engagement Innovation to Support STEM Teachers' Professional Development in Technology-Based Instruction

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ABSTRACT: This paper reports on the design, implementation, and results of a video-based study that focused on supporting an individualized viewing experience, keeping a record of what was noticed, providing a degree of guiding framework, and facilitating a combination of individual and collaborative reflections in noticing activities for STEM professional development. A cohort of 20 prospective mathematics teachers at a public university in Hong Kong participated in the study. The participants engaged in a series of blended learning activities with a feature that allowed them to leave comments while viewing of a lesson video, which focused on technology integration in mathematics classrooms. The designed activities were helpful for the participants to document and reflect on their observations, while viewing videos outside the classroom allowed them to meaningfully engage with the course materials. Moreover, the use of videos supported the participants' broad but crucial STEM classroom practices that would help them prepare for future lessons.

Keywords: Professional development, Teacher noticing, Videos, STEM education, Preservice teachers

1. Introduction

STEM education covers science, technology, engineering, and mathematics disciplines across all grade levels in both formal (e.g., classrooms) and informal (e.g., afterschool programs) settings. STEM education plays an increasingly pivotal role in all aspects of human behavior, and there is a need to improve K-12 STEM education and to support professional development for teachers in effectively delivering STEM concepts and practices in their classrooms (Chai, 2019; Lynch et al., 2019). For example, the emergence of various forms of technology enables the use of new technology in STEM education to transform the way we teach and learn. However, the mere presence of technology will not ensure the quality of education; it is imperative to support teachers with STEM education models and technology-enhanced pedagogies in order to take full advantage of technology in STEM instruction.

Teacher professional development (TPD) is crucial in all kinds of educational reform, including STEM (e.g., Desimone, 2009; Fore et al., 2015; Guskey, 2002). Parker et al. (2015) argue that STEM teachers have greater needs to develop their technological, pedagogical, and content knowledge (TPACK) than other forms of knowledge (Koehler & Mishra, 2009) and understand how different disciplines can be integrated in classrooms. In recent years, the use of video as a technological tool for developing teachers' technological and pedagogical expertise in the STEM disciplines has been on the rise (Chai, 2019). Particularly, video-based reflections have been widely adopted to facilitate productive noticing for science and mathematics teachers: the kinds of classroom events that teachers attend to, how they interpret the events they observe, and how they act on them (Chan et al., 2021; Schack et al., 2017). The construct of teacher noticing has been empirically investigated to shed light on the dynamic and situational aspects of teaching expertise that underlies teaching decisions and actions that occur in the moment (Chan et al., 2020). Coupled with video-based noticing, this approach could help pre- and in-service teachers visualize and interpret complex classroom situations and student learning in STEM classrooms. Despite positive results regarding video-based teacher reflections in professional development programs, a meta-analysis by Tripp and Rich (2012) revealed that a consensus has not been reached as to how to effectively engage teachers in video-aided reflections, particularly on the kinds of noticing tasks or reflections to be used in video-based professional development.

This paper focuses on the video-based professional development experience of preservice teachers (PSTs) in the context of integrating instructional technology in mathematics teaching. In response to the meta-analysis study by Tripp and Rich (2012), which identified a research gap in the kinds of video-aided reflections used to effectively support TPD, this paper reports a set of design-based professional development activities for PSTs that: (1) promote individualized, out-of-class video watching, (2) provide a framework that guides PSTs to notice various aspects of classroom interactions and events, and (3) facilitate a combination of individual and collaborative reflections. This design-based study aimed to evaluate a video-based technological innovation and the accompanying series of blended learning activities to facilitate productive noticing in PSTs about various

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aspects of technology integration during a teacher education course. With regards to STEM integration in the TPD, closely linked mathematical concepts and technological skills were taught in authentic classrooms to expand knowledge and skills, i.e. constituting an interdisciplinary STEM education (English, 2016). First, we describe the design and implementation of activities to promote video-based noticing in mathematics teacher education. We then present the results of these video-based noticing activities, detailing how the activities helped PSTs to meaningfully engage in noticing, make connections with course material, and express pedagogical considerations for future teaching. Finally, we discuss limitations of the designed activities and the potential for asynchronous video noticing to direct future research on teacher noticing.

2. Literature review

2.1. STEM teacher professional development

In a review of the notable trends of TPD for STEM, Chai (2019) noted that one of the most common pedagogical approaches for STEM TPD studies is the use of workshops. This approach varied in complexity; studies employed workshops only, workshops with lesson design, and workshops with lesson design/refinement and professional learning communities. The approach of mentoring was highlighted by Ufnar and Shepherd (2019), who posited that an effective TPD model should contain feature discipline content knowledge, pedagogical content knowledge, inquiry strategies, collaboration, and teacher renewal. In terms of structural features, TPD should be focused on specific grade levels and provide a variety of activity types. Parker et al. (2015) proposed five critical features of professional development for large-scale STEM urban elementary school reform: coherence, content focus, active learning, collective participation, and duration. Overall, scholars agree that STEM TPD should help teachers learn to use technology-enhanced curriculum materials and improve teachers' content knowledge, pedagogical content knowledge, and/or understanding of how students learn in technology-enhanced contexts. In particular, the design of the technology and, more importantly, the teachers' levels of adaptive expertise in helping their students learn with technological tools are important for integrating technology into STEM education (Roschelle, 2006). As such, more research is needed to help teachers to incorporate novel technologies and transform their pedagogies accordingly. This study draws on the effective TPD model of Ufnar and Shepherd (2019) and Parker et al. (2015) in supporting development of different types of knowledge through inquiry, as well as focusing on content and providing active learning opportunities (see Section 3.2). Despite the fact that extant research has examined the development of technological and pedagogical expertise in subject teaching by in-service teachers (e.g., Ng & Chan, 2021; Pilgrim & Martinez, 2015), relatively few studies focus on how PSTs develop their competence in implementing technologies that are novel to them.

Without the identification of noteworthy and important objectives in STEM lessons, PSTs cannot make relevant connections between educational theory and professional practice nor can they use these connections to make decisions (Floro & Bostic, 2017). Lee (2019) examined the lesson study approach as an effective means of TPD in initial teacher education. The lesson study involved four main stages: the investigation of students' thinking, initial lesson revision before teaching, teaching, and lesson study discussion. The lesson study method improved PSTs' ability to practice noticing when reviewing and planning lessons. The lesson study method can be coupled with videos to provide more intensive support for learning in PSTs. According to Chai (2019), video recordings were frequently used as learning tools for PSTs who otherwise lacked access to STEM classrooms; by watching videos of activities in an authentic classroom, teachers could relate the videos to their future teaching practices and thus, grow professionally. Video-based reflections have been used to complement the pedagogical strategy of teacher noticing (Radloff & Guzey, 2017) because videos can capture the complexity of classroom events that could otherwise be easily overlooked, such as critical moments during teaching and learning (Stockero & Van Zoest, 2013). For example, a study conducted by Gröschner et al. (2015) examined the effect of the "dialogic video cycle" by videotaping the participants' own teaching courses during a workshop and then discussing and reflecting in groups. They found that two independent raters strongly agreed on the implementation of effective components in the workshop. In a similar study (Radloff & Guzey, 2017), the use of videos was found to help PSTs to identify significant events in STEM classrooms, make sense of the events, and connect them to pedagogical knowledge.

2.2. Noticing in mathematics teachers

Due to their lack of classroom experience, PSTs often face challenges in planning effective lessons and interpreting students' actions and difficulties, especially when facing unfamiliar classroom contexts such as implementing technology-enhanced pedagogies during the lessons. In this regard, mathematics teacher noticing has been highlighted in practice and research for developing teachers' abilities to comprehend teaching and learning scenarios and to interpret classroom events (Choy, 2016; Jacob et al., 2010; Star & Strickland, 2008). The term "teacher noticing" comprises a set of inter-related processes, such as attending, interpreting, and deciding (Jacobs et al., 2010 Mason, 2002; Star & Strickland, 2008). For instance, the use of videos provides an effective means to foster observations, discussions, and reflections (Bencze et al., 2009). Although in-service teachers may realize that they have experienced most of what happens in the videos (Borko et al., 2008), the use of videos may help PSTs to anticipate what they might experience in unfamiliar situations, such as teaching in technology-rich classrooms. As Standen (2021) argued, one of the main critiques in educational research is the lack of connection between the knowledge production of teachers in academic settings and teachers' work practices. This is especially pertinent for initial teacher education, which is often considered to be decontextualized and far removed from teachers' every day practices. Thus, it is important to examine the relationship between PSTs' abilities to attend, analyze, and respond to their noticing in order to address the complexity of everyday STEM teaching as well as the effectiveness of video-based methods used to provide detailed descriptions of the teaching context (Barnhart & van Es, 2015; Kilic, 2018).

In the current study, we used video-aided reflection to facilitate a productive noticing experience regarding effective technology integration in classroom teaching for mathematics PSTs. The specific technology used was the 3D printing pen (hereafter, the 3D pen; Figure 1), a tool that enables one to construct artefacts in three dimensions, thereby enhancing the teaching and learning of topics in geometry, such as the volume of prisms and pyramids and cross sections of solids (Ng & Ferrara, 2020; Ng et al., 2020). The choice of 3D pens is suitable for our investigation as it is a novel technology not only for the participating PSTs but also in STEM education in general. Therefore, we were interested in how the PSTs interpreted what they noticed while watching the videos of a mathematics lesson involving the use of 3D pens as an integrated STEM pedagogy (English, 2016). Previous research has shown that video-aided teacher reflection promotes genuine engagement with student thinking and learning, thus enriching teachers' pedagogical knowledge (Jacobs et al., 2010). In this study, our first objective was to extend video-aided reflections to the context of technology-rich classrooms, considering videos of authentic 3D pen–enabled classroom episodes to have the potential to enrich PSTs' reflections. The second objective of this study was to examine the designed video-based reflection activities and lesson-refining tasks used to facilitate PSTs' TPD in a blended learning setting. We describe our design principles in the following section.

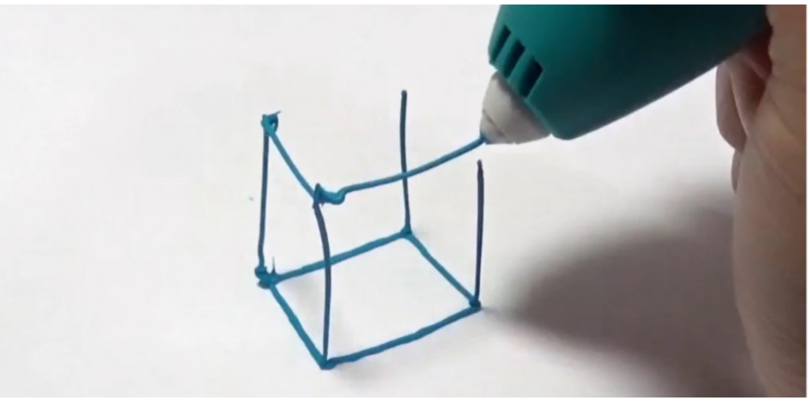


Figure 1. Drawing a cube in three dimensions with a 3D pen (see also, Ng, 2021)

3. Methodology

3.1. Participants and context

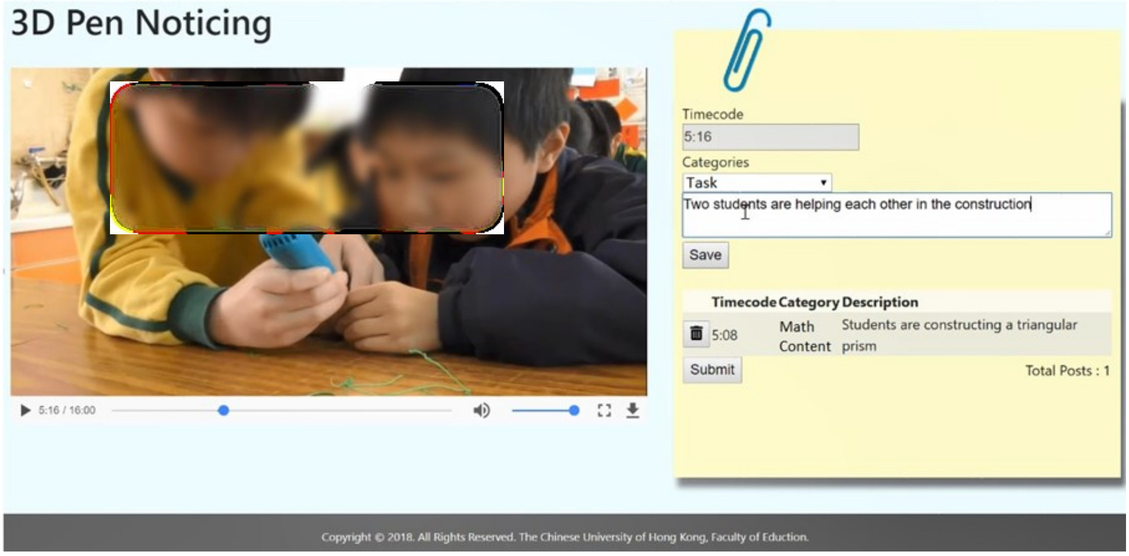
The current design-based study took place during a mathematics education course taken by 20 prospective teachers who specialize in mathematics education at a public university in Hong Kong. In the course, Mathematics Curriculum and Teaching: Instructional Technology and Design of STEM Learning Activities, an emphasis was placed on designing technology-rich learning tasks in mathematics and anticipating their use in the classroom. For example, the introduction to the use of instructional technologies, such as dynamic geometry software, 3D printing, and coding, for designing STEM learning tasks and projects was one of the major objectives of this course. To facilitate mathematics PSTs' noticing in and out of the classroom during the course of their studies, blended learning was utilized to combine classroom learning with asynchronous online learning, hence, students could, in part, control the time, pace, and location of their learning (Tucker, 2013).

3.2. Designed modules with technological innovation to support video-based noticing

With technical support from the authors' institution, the first author developed four online video modules to be hosted in the course management system, Blackboard, for the said required mathematics pedagogy course taken by fourth-year mathematics teacher education undergraduates (Table 1). Each module required about half an hour of viewing time and formed the core of class discussion for one day in class.

Table 1. Learning content of four modules designed prior to the noticing activity

Module	Objective	References
1. The discipline of noticing	To provide fundamental concepts about teachers' professional noticing and its importance for their professional growth.	Mason (2002)
2. Learning to notice for professional growth	To explain that noticing skills can be trained and differ by level of experience; to improve noticing skills by applying the observational strategies learned.	Star and Strickland (2008)
3. Professional noticing of children's mathematical thinking	To learn and practice the skills necessary for attending to, interpreting, and deciding what to do with students' mathematical thinking.	Jacob et al. (2010)
4. Mathematics teacher noticing during the task design	To introduce and apply a model for productive noticing before, during, and after lessons.	Choy (2016)


3D Pen Noticing

Timecode: 5:16

Categories: Task

Two students are helping each other in the construction

Timecode	Category	Description
5:08	Math Content	Students are constructing a triangular prism

Total Posts : 1

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Figure 2. Screenshot of the video module with the commenting feature

The design of the modules was informed by research on elements that characterize effective TPD, such as the development of different types of content and pedagogical knowledge through inquiry, the focus on content, and the provision of active learning opportunities (Parker et al., 2015; Ufnar & Shepherd, 2019). Specifically, the design aims to promote active learning and metacognitive strategies through interactions with the video-based noticing interface, which enabled PSTs to pause the video anytime, comment on what they noticed, and save the time-stamped comments instantly and conveniently. For instance, as seen in Figure 2, the video captured two students working in pairs while using a handheld 3D pen to investigate three-dimensional geometry (Ng & Ferrara, 2020; Ng et al., 2020). The rest of the video captured both the classroom teachers' and students' actions during lessons, which adopted an inquiry-based and student-centered approach to mathematics instruction. Along with describing what they noticed, the PSTs submitted their reflections via Blackboard to be stored and retrieved by the instructor for grading and for preparing class discussions in the next class session. According to the framework of Chi and Wylie (2014), the designed activities linked cognitive engagement to everyday STEM classroom practice through constructive (making notes of noticing) and interactive (discussing interpretations and opinions) modes of active learning. Moreover, this unique blended learning environment with an instant commenting feature was designed to improve PSTs' noticing in the following ways that are not afforded by watching the videos in a face-to-face class setting:

- all PSTs will participate in video commenting and reflecting;

- they will do so at their own pace;
- the instructor can assess PSTs' skills of noticing certain aspects of the video;
- the instructor can organize PSTs' comments to facilitate meaningful discussions accordingly and to plan pedagogical activities for the subsequent lesson.

The design of the interface made it possible for the instructor to customize the choice of video and categories of noticing, and this helped viewers attend to certain prescribed categories. For instance, in one of the modules, the PSTs learned about five observation categories developed by Star and Strickland (2008) as well as details of the study's findings. Then, they practiced noticing by watching an authentic lesson video while choosing one of five observation categories from a drop-down menu: classroom environment, classroom management, mathematical content, tasks, and communication. As Star and Strickland (2008) pointed out, these categories were chosen to improve teachers' video-based noticing in classroom situations, interactions, and events. Thus, PSTs could use the prescribed categories to organize what they considered meaningful in order to be more aware of different aspects of teaching and learning mathematics. Organizing their attention in certain broad categories can foster PSTs' metacognition in terms of increasing awareness and making sense of their viewing (Topcu & Ubuz, 2008). According to Tripp and Rich (2012), the predetermined observation categories could allow the students to freely identify what was personally meaningful to them. At the same time, these categories also helped students relate their noticing to specific aspects of teaching and learning mathematics in technology-rich environments. In addition, the timecode of comments allowed the course instructor and the PSTs to locate the identified episodes during the ensuing class discussions.

3.3. Blended learning activities with video-based noticing

The first author designed and implemented the following blended learning activities to accompany the four modules of the teacher education course. Before coming to class, PSTs were to watch a video consisting of two parts (10–15 min each). The first part was a lecture with a voice-over PowerPoint presentation on learning to notice and on applying noticing in mathematics teaching (Table 2). The second part featured children learning mathematics in a technology-enhanced lesson. For example, Module 2, Part 1 of the video presented conceptual ideas and empirical findings for directing PSTs' attention to productive noticing, so they could practice their noticing while watching students' activities in Part 2 of the video, which captured the beginning and end of the lesson, including episodes of the teacher leading whole-class discussions to convey instructions, introduce relevant mathematics concepts, and present the activity. Therefore, the video summarized key aspects of the lesson and aspects consistent with the observation categories developed by Star and Strickland (2008).

While watching Part 2, PSTs commented using the eLearning system, Blackboard, on what they noticed. In addition, they were asked to engage in a lesson reflecting activity after completing each module. The lesson reflecting activity prompted them to reflect on various aspects of the lesson. The prompts used in this activity were drawn from the work of Mason (2002), who argued that there are two requirements for professional noticing. The first requirement is to make "account of" (i.e., reconstruct observations step by step and describe some incidents from the video briefly but vividly), and the second requirement is to "account for" (i.e., offer interpretation, explanation, value, judgement, justification, or criticism on the accounts). This two-part noticing task was intended to help PSTs make the distinction between the two constructs by interpreting the accounts and then asking "why" (Mason, 2002).

At the end of all four modules, the students completed a final assignment to cohesively apply their learning from the modules. In this lesson planning activity, they planned a technology-enhanced mathematics lesson of their choice. In particular, the lesson plan was to contain details of materials (including the target technology) used and how it would be used, the target concepts to be learned and how they would be developed during the lesson, anticipation of students' and teacher's actions, and justifications of the lesson design. The assignment design was aligned with research-based principles of developing metacognition through a cycle of reflecting, assessing, evaluating, planning, and applying (Ambrose et al., 2010).

3.4. Data collection and analysis

The data collection and analysis methods were consistent with design-based research (DBR), having "the intent of producing new theories, artefacts and practices that account for and potentially impact learning and teaching in naturalistic settings" (Barab & Squire, 2004, p. 2). The design aspect of this DBR study was a series of video-based blended learning activities used during the course for the PSTs. An important goal of DBR is to impact practice directly through iterative cycles of lesson design, enactment, analysis, and redesign. The data reported in this study was collected from the second cycle of lesson design and enactment, after an analysis of the lesson enactment in the first cycle during the previous year. With respect to developing empirically grounded theories, this study intends to advance the concept of teacher noticing in technology-enhanced classroom contexts through qualitative investigations of PSTs' development in various types of knowledge: technological, pedagogical, and content.

Before the first lesson, the first author obtained informed consent from the PSTs enrolled in the aforementioned course. The data obtained in this study included records of the PSTs' participation in the blended learning activities (time-stamped noticing comments and reflective writing) as well as field notes gathered during whole-class discussions on video-based noticing. The data were collected based on the principle that this study is beneficial to the participants' learning experiences and poses no known conflict of interests to them.

The large amount of textual data obtained from the blended learning activities was organized and then analyzed using thematic analysis (Hatch, 2002) in order to "generate plausible themes based on a plethora of evidence and paucity of counter examples" (Floro & Bostic, 2017, p. 79). A thematic analysis coupled with the use of constant comparative strategies (Strauss & Corbin, 1990) is appropriate in qualitative studies because it facilitates data analysis according to commonalities, relationships, and differences (Gibson & Brown, 2009). The authors reviewed the data in its entirety. Then, common patterns were organized into initial, tentative themes, namely: (1) guided noticing of STEM teaching and learning, (2) individualized noticing and in-depth reflection of STEM lessons, and (3) noticing structuring features of STEM classroom practice. At this stage, triangulation of data was performed by seeking supporting (or non-supporting) evidence within individual responses written by PSTs from different data sources (i.e., time-stamped noticing comments, reflective writing, and whole-class discussions). The authors went over the data a second time to explore the degree to which general patterns matched the data. Based on these patterns, themes were generated to describe the PSTs' professional growth stimulated by the designed video-based noticing activities.

4. Results

We report the DBR results based on the PSTs' engagement of Modules 2 and 3, Learning to Notice for Professional Growth and Professional Noticing of Children's Mathematical Thinking. In these two modules, the number of noticing comments for each PST ranged from 12 to 38, with interaction time ranging from 45 min to 1 h 42 min. Considering that modules were roughly 20 min long, the PSTs had varied levels of engagement with the video. For instance, some PSTs watched the video in one sitting while others rewatched the video multiple times in order to write detailed comments on their observations. In the following section, we report on our second DBR implementation cycle of facilitating video-aided professional development in STEM education.

4.1. Guided noticing of STEM teaching and learning

During Module 2, PSTs were tasked with choosing from five observation categories as prescribed by the noticing task. Table 2 illustrates their observations on a lesson video during which 3D pens were used. Based on the total number of comments made under each category, PSTs generally paid more attention to tasks (91 times) and mathematical content (79 times), followed by classroom management (61 times) and communication (60 times). They paid the least attention to classroom environment (30 times), and this was consistent with the results of Star and Strickland (2008) who also found that PSTs are less competent in attending to the classroom environment.

As shown in the noticing comments presented in Table 2, some PSTs' noticing converged when guided by the noticing task. For example, PSTs 3 and 4 noticed the same classroom routine (i.e., clapping hands) used by the teacher in the video around the 12:40 mark to draw students' attention and maintain control of the classroom. Similarly, PSTs 5 and 6 commented on the same mathematical content in which the teacher was helping his students make "generalizations" about the number of vertices, edges, and faces "in any prism". Although both PSTs 5 and 6 commented on the same part of the video, PST 6's noticing was more detailed than that of PST 5. The video noticing interface with predetermined observation categories were helpful for the PSTs to focus on various classroom events, thereby broadening their considerations for different aspects of teaching and learning mathematics. At the same time, it afforded high video engagement and helped PSTs describe details of the viewed content.

Table 2. Examples of PSTs' time-stamped comments with chosen categories of noticing

Categories	Comments
Classroom environment	• "Keywords going to be taught are already written on the blackboard" (PST 1, 3:19). • "The teacher sets a timer (8 min), and students are allowed to focus on their task to draw the prism. Some students get involved quickly in the activity" (PST 2, 3:43).
Classroom management	• "The teacher uses some classroom routines (clapping three times) to attract the attention of students; students respond accordingly" (PST 3, 12:45). • "The teacher used a ring to call students back from group work and attracted students' attention by clapping" (PST 4, 12:40).
Mathematical content	• "The teacher generalized the pattern of how many Vs, Es, and Fs there are in any prism" (PST 5, 15:28). • "After generalizing results, the teacher asked students about hexagonal prisms. Students answered quickly and could make good reference with the previous results, concluding that any prism has the same number of lateral faces as the number of sides of the base" (PST 6, 15:44).
Task	• "The teacher kept checking on the progress of students and checking the students' work" (PST 7, 10:02). • "Students were encouraged to think about the teacher's question based on how they drew with the 3D pens" (PST 13, 14:11)
Communication	• "A student was trying to help the student who was holding the pen to fix the object, but she refused" (PST 10, 5:19). • "The teacher asked each group of students to take one prism and told students to turn off the 3D pen" (PST 14, 14:59).

We were also interested in the extent to which the PSTs noticed the connection between pedagogy and content when 3D pens were used in the video. To this end, we located 28 comments that included the words "3D pens" or "3D Printing"; 11 of them were attributed to the category of tasks, six to mathematical content, six to communication, four to classroom management, and one to classroom environment. Based on these comments, we characterized the knowledge demonstrated by the PSTs into technological knowledge (TK), technological content knowledge (TCK), and TPACK based on the framework by Koehler and Mishra (2009; Table 3).

Table 3. Examples of PSTs' time-stamped comments about 3D pens and the types of knowledge demonstrated

Types of knowledge	Comments about 3D pens/printing
Technological knowledge (TK)	• PST 2: "The teacher asked each group of students to turn off the 3D pens" • PST 9: "They used scissors to cut unnecessary 3D printing"
Technological content knowledge (TCK)	• PST 7: "Students used the 3D pen to draw the base of the prism first while some drew the lateral face first" • PST 12: "The use of 3D printing allowed students to investigate some properties of triangular prisms on their own (e.g., the number of edges)"
Technological pedagogical content knowledge (TPACK)	• PST 5: "Students tried to complete the table on the blackboard with the use of the prism they made with the 3D pen; this enabled them to visualize the prism" • PST 6: "The teacher linked the imagination of a pentagon cylinder with the experience of the 3D pen activity" • PST 8: "The teacher tried to encourage students to think of alternative methods to create a prettier 3D figure while students were trying to make an appropriate figure"
Other knowledge pertaining to aspects (characteristics) of the learner; learning environment	• PST 8: "A group of two students got only one 3D pen, and some of them cooperated with each other while some were just looking at their partner" • PST 3: "The girl grabbed the 3D pen from the boy"

4.2. Individualized noticing and in-depth reflection on STEM lessons

When given more time for noticing, the PSTs generally recorded more precise and frequent "accounts of" noticing before moving onto the reflection task ("accounting for"; Mason, 2002). This stood in contrast to watching the videos in class, where the PSTs were quick to share their interpretations and judgements (e.g., "I feel that . . .") before sharing their observations, and this could hinder the development of noticing skills.

Moreover, out-of-class viewing allowed for extra time to reflect on the video or even to revisit the course material before "accounting for" what was watched. During the reflection task, they demonstrated fluency in making connections between the video and course content by analyzing crucial aspects of classroom practices for mathematics teaching and learning. A PST's reflection exemplifies this observation:

The student [in the video] seemed to have wrongly recognized a pyramid as a prism. It is a common mistake made by students when a prism is placed in a different way as they would wrongly recognize a side of a triangle as the apex of a triangular pyramid. [I suggest] asking students to recall the characteristics of prisms and pyramids. Then I'd ask students to have a quick check to see if the object fulfills all the conditions.

The above quote illustrates that, upon watching the video, the PST had diagnosed a "mistake" made by a student in the video ("attending to children's strategies" [Jacob et al., 2010]), made sense of why it might have happened ("interpreting children's understanding"), and made decisions about teaching this topic in the future ("deciding how to respond on the basis of children's understandings"). Therefore, she had anticipated the content in Module 3 (i.e., the definition of "professional noticing of children's mathematical thinking" by Jacob et al., 2010) to reflect on her noticing. This shows how PSTs, when given the prompt and time to engage in individualized noticing, can make meaningful connections with the course material. In addition, the PST linked her noticing to other course content, namely, "structuring features of classroom practices" (Ruthven, 2009). According to Ruthven (2009), she paid attention to the "curriculum script" as a sequence of goals, actions, and expectancies (including the expected difficulties and alternative paths) for teaching a curricular topic. Moreover, she "developed ways of staging [. . .] and managing patterns of student responses" (p. 387) to support mathematics learning through this noticing activity. As shown in these observations, the blended learning environment enabled PSTs to participate in noticing at their own pace, and this helped them thoroughly reflect on their learning as opposed to spontaneously reflecting on the video as a group.

4.3. Noticing structuring features of STEM classroom practice

Complementary to the course aims, the students applied pedagogical frameworks learned during the course to make sense of elements that underpin the successful integration of technology in mathematics classrooms. In their reflections, for example, they referred to the "working environment," "resources systems," and "activity structure," as proposed by Ruthven (2009), as structuring features in which teachers integrate (or fall short of integrating) new technologies into classroom practice. By analyzing these crucial aspects of classroom practices, they improved their knowledge on incorporating technology into mathematics lessons, as illustrated in the following reflection by PST 3 (see Table 4).

Table 4. PST 3's reflections about STEM classroom practice

Structuring feature of classroom practice	PSTs' making account of their noticing	PSTs' accounting for their noticing
Resource System	1. A real-life object (a rectangular prism [i.e., food packaging]), 2. A set of 3D pens for the student activity (constructing triangular prisms), 3. A set of premade pentagonal prisms made by the teacher using a 3D pen	1. Provided real-life situations for students to observe the number of faces of a prism 2. Enabled students to have hands-on experience with prism construction 3. Provided another example for further observation on the relationship between the number of faces and lateral faces of a prism

As seen in the above reflection, PST 3 paid attention to "resource systems" (Ruthven, 2009), a collection of didactical tools and materials used by the teacher. Accounting for the "resource systems" used, PST 3 reflected on the coordination of use towards achieving curricular goals. Importantly, PST 3 not only commented on the impact of using 3D pens but also on more traditional teaching aids such as real-life objects and premade prisms used to enhance student learning. Hence, PST 3 reflected on each resource in detail and on their use as a system for learning the properties of prisms. In the terms of Ruthven (2009), through this noticing activity, PST 3 made sense of "appropriate techniques and norms for use of new tools to support subject activity," and "the double instrumentation in which old technologies remain in use alongside new" (p. 387).

Importantly, PSTs' decision-making regarding their future teaching practices was justified by what they observed and learnt from the video modules. In general, after observing students' mathematical thinking in a technology-based task in Module 3, the PSTs positively evaluated the effectiveness of technology-enhanced learning: "It is easier to find the relationship of the cross-sections along similar cuts using 3D pens" (PST 7). On the other hand, in their decision-making, students reflected on learning difficulties and "hiccups" (Clark-Wilson & Noss, 2015) that arose in tool-based learning situations. For example, one student commented that there was room to "develop an extension question to test whether the student can understand and think correctly" (PST 7). It is expected that these observations will be considered in the PSTs' future lesson plans, promoting quality implementations of technology-enhanced lessons.

5. Discussion

As shown in the results, the PSTs applied course content to consider and reflect on technology integration in mathematics teaching. For example, they critiqued the lesson video with respect to: the lesson and task design, technology use, how mathematical concepts unfolded, and student engagement and communication during the lesson. Their noticing was generally rich in terms of variety, as shown by the observation categories analyzed, as well as personal and meaningful in terms of making connections to technology-enhanced pedagogy. This can be traced to the method of individualized video-based noticing to enable PSTs to visualize themselves as the teacher in the lesson while they were guided by reflection prompts, which facilitated discussions on how the lesson could be improved.

In turn, the PSTs were able to formulate an effective lesson and to pinpoint the enhancements made in the lesson afforded by the 3D pens. This demonstrated their growth of TPACK (Koehler & Mishra, 2009), in the sense of both gaining an understanding of how 3D pens are used to create 3D solids (i.e., TCK) and can be used for teaching and learning (i.e., TPK). They also realized how certain learning activities with 3D pens could support student learning of geometrical concepts (i.e., TPACK). The use of videos seems to be instrumental for PSTs' professional growth as it provided extensive imagery of technology-rich classroom contexts and classroom activities through episodes of teaching and learning and key moments of the technology-aided lesson. In relation to the key dimensions of video-aided teacher reflection proposed by Tripp and Rich (2012), the designed activities achieved individualized, out-of-class video watching and guided noticing in PSTs about various aspects of technology-enhanced mathematics learning. Scholars (e.g., Knolton, 2014; Pilgrim, 2015) have argued that various learner aspects and contextual features are not addressed in the TPACK framework despite their significance in teaching and learning. The PSTs' comments in this study reiterated the importance of teacher knowledge or understanding of their target learners and learning environment. PSTs' comments beyond the conventional TPACK framework should be further analyzed and categorized to better understand PSTs' various types of knowledge involved in the design and implementation of the target lesson.

Besides the benefit of individualized viewing, the ability to store PSTs' noticing comments on Blackboard allowed us to assess and differentiate noticing in PSTs and to facilitate class discussions based on commonalities and differences. For example, some PSTs noticed more subtleties in one category than other categories while completing Module 2, and so we facilitated group discussions in the ensuing class focusing on the commonality or lack thereof of PSTs' noticing. As a result of the discussions, they realized that they were most concerned with classroom management issues related to implementing technology- and inquiry-based learning activities. Hence, they further discussed different classroom management strategies that could be implemented to enhance the lesson watched. Another discussion unfolded, in which some PSTs acknowledged that their previous schooling experience might have influenced their "viewing lens". They also reflected on their strengths and weaknesses regarding noticing as well as their plans to improve their future teaching practices. Lastly, the categories of noticing facilitated a meaningful class discussion about what should be considered communication, classroom management, and tasks, and the possible overlap of two or more categories in a single noticing act. This was interesting because these had not been brought up in face-to-face video sessions in our prior experience of teaching in a fully face-to-face format. Overall, we were satisfied with the participation level of these discussions, as it seemed that PSTs were prepared to engage in group discussions and class time was consequently optimized.

In relation to advancing teacher knowledge and the concept of teacher noticing, we highlighted two methodological choices that helped to explain the results: (1) two requirements of noticing proposed by Mason (2002), which prompted the teachers' interpretation ("accounting for") upon recollecting ("made accounts of") what they saw in the video; and (2) conducting class discussion after individual viewing. The first choice allowed the PSTs to become conscious of the connections they were drawing between specific classroom episodes and principles of teaching and learning and to reason about classroom events (Star & Strickland, 2008). The second enabled the researchers to observe changes in the teachers' expertise as a collaborative and social process. During the classroom discussions, the PSTs guided each other's attention, interpretation, and decisions regarding STEM teaching and learning. These empirically grounded results inform future STEM professional development programs on two effective methodologies for developing teacher expertise in STEM and technology-enhanced pedagogies.

Although the design-based implementations yielded some satisfactory results, they had some trade-offs. While individualized, out-of-class video watching could potentially facilitate a more prolonged engagement with the video content and reflection, not all PSTs took advantage of it. Some commented as little as 12 times in one video module. Similar to the findings of Krammer et al. (2006), our findings showed that some PSTs commented that typing comments and reflections took up too much time. In contrast, in-class noticing activities are more effortless since they are completed verbally, though participation and engagement levels will vary amongst PSTs. Finally, it seems that the various activities favored different kinds of class discussions; in-class noticing promoted more spontaneous, personal discussions and blended learning prompted more planned, theoretical discussions.

6. Conclusion

In this paper, we discussed the design, implementation, and results of a video-based STEM professional development intervention that focused on supporting an individualized viewing experience, keeping a record of what was noticed, providing a guiding framework, and facilitating a combination of individual and collaborative reflections. The use of the designed blended learning activities with a feature that supports instant commenting enabled mathematics PSTs to document and reflect on their noticing, and out-of-class video watching allowed them to engage and make connections with the course materials meaningfully. In addition, the prescribed observation categories of video-based noticing addressed various broad but crucial aspects of STEM classroom practices that aimed to help PSTs prepare for their future teaching careers. Aligned with previous research on video-based noticing (Jacob et al., 2010; Ng & Chan, 2021), the videos captured the dynamic processes of students' actions rather than just their final "answer," and this facilitated the participants' reflections about the evolution of students' mathematical thinking.

The designed innovation with blended learning activities effectively drew the attention of PSTs to different aspects of technology-enhanced mathematics instructions, but the innovation was not limited to addressing such contexts. Future TPD programs and research can use video-based noticing to develop teachers' expertise in other STEM areas, particularly those that are unfamiliar and not easily accessible by teachers in their everyday teaching. Researchers can also investigate whether the use of videos can influence teachers' perceived efficacy of teaching STEM after the blended learning activities.

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