Considering How to Use First Principles of Instruction and Video Technologies to Support Teachers' Professional Learning in Mathematics Education[1]

Considerando cómo utilizar los principales principios de la instrucción y las tecnologías de vídeo para apoyar el aprendizaje profesional de los maestros en educación matemática

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Abstract
Merrill's First Principles of Instruction provide a framework for the design of learner-centered instruction. In this article we examine how those Principles of Instruction provide a framework to examine effective ways to leverage the use of video technologies to enhance the design and implement professional learning for mathematics teachers. We synthesize the First Principles of Instruction, the Launch-Explore-Discuss lesson cycle in mathematics (Polly, 2017b; Tools4NCTeachers, n.d.), and principles of learner-centered professional learning (Polly & Hannafin, 2010). We then describe vignettes about how video technologies can enhance professional learning experiences that align to the First Principles of Instruction and learner-centered professional learning. We close with implications and recommendations for research and practice for future endeavors.
Keywords: principles of instruction, video technologies, teachers' professional learning, mathematics education.
Resumen
Los *principales principios de instrucción* de Merrill proporcionan un marco para el diseño de instrucción centrada en el alumno. En este artículo examinamos cómo esos Principios de Instrucción proporcionan un marco para examinar formas efectivas de aprovechar el uso de tecnologías de video para mejorar el diseño e implementar el aprendizaje profesional para los profesores de matemáticas. Sintetizamos los Primeros Principios de la Instrucción, el ciclo de lecciones Launch-Explore-Discuss en matemáticas (Polly, 2017b; Tools4NCTeachers, s.f.), y los principios del aprendizaje profesional centrado en el alumno (Polly y Hannafin, 2010). Luego describimos viñetas sobre cómo las tecnologías de video pueden mejorar las experiencias de aprendizaje profesional que se alinean con los Primeros Principios de Instrucción y el aprendizaje profesional centrado en el alumno. Cerramos con implicaciones y recomendaciones para la investigación y la práctica para futuros esfuerzos.
Palabras clave: principios de instrucción, tecnologías de video, aprendizaje profesional de los docentes, educación matemática.

[1] Author Note: Prior to passing away in 2020, Michael J. Hannafin contributed many of the ideas that are included in this paper. It is with respect and gratitude that we include him as a co-author.

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Mathematics Learning in the United States

United States students' performance on large-scale measures of achievement have drawn criticism and created alarm among policy makers and scholars for the past few decades (U.S. Department of Education, 2020; OECD, 2018). Compared to other developed nations the United States students performed less than many well-developed countries (OECD, 2018). Additionally, there has been only modest gains on students' achievement on national and state assessments (USDE, 2020).

More alarming in the United States is the drastic disparity between students' achievement between those who identify as African-American, Black, Brown, or Latinx, compared to those who identify as White, Caucasian, or Asian (Polly et al., submitted; Young et al., 2021). In response to these disparities, many scholars have called for more intentional efforts for teachers' professional development and professional learning (hereafter teacher professional learning or TPL) related to preparing teachers of all students, especially those who are performing below grade level expectations, to use more learner-centered, constructivist-oriented approaches to mathematics learning that provide learners with agency, choice, and access to exploring high-quality mathematical tasks (Polly & Hannafin, 2010; Borko, 2006; NCTM, 2014).

Access to high-quality TPL varies across the world. The use of video to support professional learning has been documented and has further potential in need of exploration (Hannafin et al., 2014; Polly & Hannafin, 2011; Tripp & Rich, 2012). In this article we use Merrill's first Principles of Learning and the empirically-based framework of learner-centered professional development, also known as learner-centered professional learning (Polly & Hannafin, 2010), to examine how video can be used as a vehicle to support teachers' learning related to their use of research-based mathematics teaching practices. We begin by synthesizing Merrill's first Principles of Learning (Merrill, 2007) and learner-centered professional learning (Polly & Hannafin, 2010). Then we discuss already documented uses of how video can support teachers' professional learning and opportunities that require further exploration. We close by helping readers to make sense of the examples provided in light of Merrill's First Principles of Instruction and the framework of learner-centered professional learning.

Theoretical Considerations

This article on teacher professional learning (TPL) is grounded first in what the mathematics classroom should look like from Kindergarten through Grade 12. In order to describe that we draw on Merrill's First Principles of Instruction (2007) and the empirically-based launch-explore-discuss learning cycle for lessons in mathematics education (NCTM, 2014; Polly, 2017; Tools4NCTeachers, 2019).

Merrill's First Principles of Instruction

Merrill advanced the ideas of First Principles of Instruction as an interrelated and interdependent set of principles that increases the likelihood of effective teaching and student learning. The Principles are detailed in Table 1.

Table 1: Overview of the First Principles of Instruction (Merrill, 2007)

First Principles of Instruction	**Learning is more effective when learners are...**
Task/problem centered	Given tasks and problems that are embedded in meaningful and relevant experiences
Activation	Provided with opportunities recall prior knowledge, given a structure for organizing that knowledge, or participate in a foundational learning experience
Demonstration	Able to observe and analyze a demonstration or example of knowledge and skill being applied
Application	Able to perform real-world tasks or solve real-world problems with immediate feedback and guidance
Integration	Encouraged to integrate and apply new knowledge into their own context through reflection, discussion, debate, or other relevant tasks

In this study we apply Merrill's First Principles of Instruction as a broad content-agnostic framework related to organizing mathematics classrooms. Merrill's Principles are based on the idea that learning is most effective when it is rooted and grounded in real-world tasks and problems. This aligns to elements of learner-centered mathematics teaching that are informed by the constructivist perspective emphasizing that mathematics learning occurs through the exploration and discussion of mathematics tasks and not traditional teacher-directed instruction (Polly, 2017; NCTM, 2014). In these lessons, the teacher should engage students in a Launch-Explore-Discuss (LED) learning cycle where the teacher launches a task by introducing a math problem or task to learners, makes connections to prior learning or real-life contexts, and checks for students' understanding before letting them explore the task. During the exploration learners collaborate to solve the problem while the teacher supports students through questioning. Lastly, after students have had ample time to explore, the teacher provides an opportunity for students to share their strategies, discuss the task, and the students take on the role of demonstrating and discussing strategies. A synthesis of Merrill's First Principles and the Launch-Explore-Discuss learning cycle is provided in Table 2.

Table 2: Comparison of Merrill's First Principles of Instruction and the Launch-Explore-Discuss (LED) Learning Cycle in Mathematics Education

First Principles of Instruction	**Launch-Explore-Discuss (LED) Learning Cycle in Mathematics Education**
Task/problem centered	The learning cycle is dependent on the use of meaningful and relevant tasks.
Activation	**Launch:** The teacher launches the task by posing it to students, asking students clarifying questions, and helping students to see connections to real-life contexts and/or previous mathematics concepts. **Explore:** Learners collaborate together to explore a mathematical task, which Merrill calls a "foundational learning experience."
Demonstration	**Discuss:** Learners share their strategies for exploring and solving the mathematical tasks with the class. The teacher facilitates the discussion, and if needed, can provide another example.
Application	**Explore and Follow-up Tasks:** Learners are solving mathematical tasks with scaffolding and support from their peers and the teacher.
Integration	**Follow-up Tasks:** Learners engage in follow-up tasks after the Launch-Explore-Discuss learning cycle to continue to practice and apply their knowledge of the mathematics concepts.

The only disconnect between the First Principles of Instruction and the LED learning cycle is the Demonstration Principle, since Merrill posited that teachers may need to demonstrate or provide a model performance for the learners to observe and analyze. In mathematics education, while the teacher could provide that demonstration, many scholars advocate for student-centered and student-driven discussions where the students share their strategies or demonstrations on how they solved the task (Hufferd-Ackles et al., 2014; Smith & Stein, 2018). The teachers' role in mathematics then is to select which learners share their strategies, sequence them in a way that makes sense, and help students to see connections and differences between the strategies through questioning (NCTM, 2014; Smith & Stein, 2018).

Applying Merrill's First Principles of Instruction to Teacher Professional Learning (TPL)

Just as Merrill's First Principles of Instruction was compared above to the empirically-based Launch-Explore-Discuss (LED) learning cycle for mathematics instruction, the Principles also need to be connected to the research base on Teacher Professional Learning (TPL). While the most well-known and well-cited TPL studies and syntheses are over a decade old these articles are still relevant and applicable today. Table 3 provides an alignment between Merrill's First Principles of Instruction and the research base on TPL.

Table 3: Alignment of First Principles of Instruction to Characteristics of Learner-Centered Professional Learning

First Principles of Instruction	**Characteristics of Learner-Centered Professional Learning (Adapted from Polly & Hannafin, 2010)**
Task/problem centered	**Relevant:** TPL should be relevant to all participants and focused on specific topics of interest or topics that relate to data on their students (Darling-Hammond et al., 2017).
Activation	**Active-engagement:** TPL should include active engagement of all participants and be situated in participants' contexts or situations that are very similar to their actual contexts (Borko, 2004; Garet et al., 2001) **Focused on content and practice:** TPL should be focused on specific content and/or instructional practices (Darling-Hammond et al., 2017).
Demonstration	**Collaborative:** TPL should include collaboration with other teachers and mentorship from more knowledgeable others to support participants' sense making of this new knowledge and skills (Glazer et al., 2009; Polly, 2014)
Application	**Classroom-based:** TPL should be ongoing and include opportunities for participants to apply their new knowledge and skills with their own students with mentorship and support (Baker & Knapp, 2019; Campbell & Malkus, 2011).
Integration	**Reflective:** TPL should include opportunities for participants to reflect on their experiences applying their new knowledge and skills with their own students and make plans and goals for future activities (Núñez Pardo & Téllez Téllez, 2015).

Congruent with Merrill's First Principles of Instruction, research on TPL calls for teachers' experiences to be situated in meaningful and relevant tasks.

The Role of Video to Support Effective Teacher Professional Learning

As we consider how to use video as a tool in teacher professional learning (TPL) to support teachers' use of the LED lesson plan cycle in mathematics, it is important to examine ways that video has historically been used in professional learning. Videos have been used in education to show examples of specific practices and to analyze one's own teaching practices.

Video to Show Practice

Background

Early applications of video primarily involved the capture of teaching practices to show teacher candidates and practicing teachers about specific instructional practices that were deemed to be "effective." Videos of "expert teaching" were collected and shown in teacher education programs and professional learning projects (Sherin, 2000).

Beginning in the 1980's, digital video emerged as a prominent media to capture and store classroom teaching and learning activities. Educators and educational leaders used video to share, distribute, and examine classroom practices (Sherin, 2003). Teacher candidates and practicing teachers would sit in courses or workshops and watch videos. This was often followed by an analysis of specific instructional practices, why they were effective, and how to apply those pedagogies in their own classrooms.

Historically, it was easy and common for teachers to attend professional learning about a new strategy or pedagogy that either administrators or district leaders wanted teachers to use, and during workshops teachers watch videos as part of that process (Sherin, 2000). The variance in professional learning experiences is how the video and other activities are sequenced and used to develop teachers.

Examples of Using Videos to Show Specific Practices

Example 1. Due to COVID-19, all of the sixth grade mathematics teachers attend a grade level meeting on Zoom with the Assistant Principal to discuss the upcoming unit on ratios and proportions. The classroom teacher who was leading the meeting projects the following task on a projector: *A car can go 25 miles per gallon of gas. How many gallons of gas are needed to go 180 miles? Find your answer. Then use a different strategy to see if you get the same answer.*

In breakout rooms, teachers spend time exploring the task in pairs while solving the problem using various strategies. The teacher leading the meeting then asks some teachers to share their strategies and helps them to unpack the math task. Everyone then watches a 6-minute video in which a 6th grade student shares an incorrect answer during a discussion and the teacher poses questions to the student on how to elicit their thinking and encourage them to revisit their strategy en route to the correct answer.

After watching the video, the teachers discussed the teachers' actions in the video and then discussed common misconceptions that they would expect students to have, including not being able to start the problem, doing an incorrect strategy, or making a computation error. The teachers then made plans to use that math problem with their students in the next day or two, and return next week with student work to discuss students' understanding.

Example 2. In a professional learning session on Zoom, teachers watched a commercially-made video of a teacher posing a word problem and supporting students by asking questions instead of giving direct instructions. Before the meeting students had independently solved the mathematics problem and come up with examples of misconceptions that students would likely make. The teachers then discussed the instructional strategies that they observed, what they thought was relevant, and questions that they had about applying these instructional strategies in their own classroom. Teachers then looked at a different math problem that they were going to pose to their students and discussed how they were going to support their students by asking questions, just like the video showed. Teachers planned to implement the mathematics problem that they discussed and come back next week to debrief their experience.

Alignment of Showing Videos with Principles of Instruction

Merrill (2007) emphasized the importance of a common experience or common framework early in the learning process as part of the Activation Principle. In the first example above teachers participated in a common experience by exploring the mathematics task, while in the second example, which was a bichronous experience with both synchronous and asynchronous experiences (Martin et al., 2020), teachers had a common experience prior to the professional learning experience in an independent setting when they solved a mathematics task and came up with possible student misconceptions. A common learning experience is emphasized by Merrill's Activation Principle (Merrill, 2007) and also aligns with the framework of learner-centered professional learning (Polly & Hannafin, 2010) since the experience was focused on specific content, relevant to teachers, and included an active learning experience.

The difference in the two examples above was where the video was included in the professional learning. In the first example the video was used as part of the Demonstration Principle as it provided an example of how a teacher can question students who have an incorrect answer to support their mathematical learning. However, in the second example while it served as an example, the professional learning facilitator of the second example chose to include the video as the common experience and then discuss the task. In both examples, the Application and Integration Principles were used afterwards as teachers made plans to pose the same math problem to students and then come back to the group with student work. In this example video was used to show teachers' practice after an instructional event focused on the Activation Principle.

While video has a lot of potential to support mathematics teachers' professional learning there is a lot of variance in how the video is used and what other activities teachers are engaged in. As seen in both examples, teachers watched videos of others enacting specific instructional practices and made plans to go and enact them in their classroom, which aligns to both the First Principles of Instruction as well as the framework of learner-centered professional learning.

Analyzing Videos of Teachers' Own Practice

Another use of video in professional learning is to analyze one's own practice by viewing and reflecting on their video in a professional learning experience (Rich & Hannafin, 2009; van Es & Sherin, 2008). Research on this approach indicates that teachers learn a lot from these types of activities. In one study, after a semester-long video reflection group teachers reported that the process of analyzing their own teaching on video helped them to focus their analysis, see their teaching from a new perspective, get more specific feedback on how to change their practice, and see their progress during the semester (Tripp & Rich, 2012). Research on video clubs where teachers collaboratively view and analyze videos of their own teaching indicated that teachers became increasingly analytical and reflective in classroom interactions among themselves and students, and promoting mathematical thinking (van Es & Sherin, 2010). In one study, some teachers initially failed to change their practices until completing a yearlong project, whereas a few immediately adopted recommended pedagogies (van Es & Sherin, 2008).

Additionally, the United Kingdom's National Council for Excellence in Teaching Mathematics (NCETM) concluded that video-based approaches to professional learning "videos produced by teachers themselves for use in their own schools, suggesting focused efforts may well be more important than 'universal' or standardized video recordings for general consumption (Hall & Wright, 2007, p. 11). Coles (2013) noted that teachers preferred examining their videos with colleagues in order to discuss professional learning sessions during live and post-lesson feedback.

Examples of Teachers Viewing Videos of Themselves

Example 1. In an after school professional learning meeting, middle grades mathematics teachers joined a Zoom session on their laptops and a 10 minute video of a mathematics discussion that they facilitated with their students from earlier in the week. The meeting begins by analyzing and unpacking a list of "Look fors" related to characteristics of effective mathematics discussions that align to topics that were discussed in a previous meeting. The list aligns to a book that all of the teachers had been reading and discussing during monthly meetings for the past three months. Teachers then work in pairs in breakout groups to examine their video with a critical friend. As they both watch the video independently they fill out a "look for" sheet where they chart and keep track of specific practices that they see in the video. Afterwards the pairs watch the video, the whole group discusses "glows" or successful implementation of practices on the "look for" sheet. Lastly, teachers make individual goals for something to work on before the next meeting which is a month away.

Example 2. In an online professional learning experience teachers videotape themselves facilitating a mathematics discussion and then submit it electronically to the facilitator. The facilitator provides initial feedback and the teachers then individually watch the video and respond to the feedback. The teachers then spend time making a goal for the enactment of future instructional practices and submit a total of 3 videos during the four month period. During the entire program teachers are participating in bichronous, i.e., a combination of asynchronous and synchronous modules (Martin et al., 2020), modules related to how to facilitate a mathematics discussion.

Alignment of Analyzing Videos of One's Own Teaching with Principles of Instruction

In the examples above videos of teachers' own teaching served as the anchor of their professional learning experience. In the first example teachers' had a common structure to evaluate the videos with the "Look fors" (Activation Principle) and then spent time examining their own video with a colleague or critical friend. Following that experience teachers spent time making a plan for implementation (Application Principle) before revisiting their experience in the next meeting (Integration Principle). The first example did not have a long activity aligned with the Demonstration Principle during the session, but the content and examples of what an effective mathematics discussion occurred in a prior session.

In the second example teachers had previously had common experiences with a book study that they had discussed and learned about characteristics of effective mathematics discussions (Activation and Demonstration Principles). There is no peer interaction, but through feedback from the professional development facilitator, the teachers received feedback on their videos and self-evaluated their videos. Similar to the first example, teachers make plans to apply their feedback in future teaching (Application Principle) and then engage in the same cycle of feedback with the facilitator to reflect on their video (Integration Principle).

In the next section we synthesize the examples and offer recommendations for the future use of video with the lens on the First Principles of Instruction and

Discussion and Looking Ahead

Table 4 shows a summary of the examples organized by the First Principles of Instruction. The use of video provided teachers with access to other people's instructional practices and also provided teachers with an opportunity to reflect on their video in synchronous and bichronous professional learning environments. With the ambitious goal of preparing teachers to effectively enact recommended mathematics practices, the lenses of Merrill's First Principles of Instruction (Merrill, 2007) and learner-centered professional learning (Polly & Hannafin, 2010) provide complexities that warrant further discussion. In this section we discuss the following complexities: 1) achieving a common understanding of the goals of professional learning, 2) the use of video in the future, and 3) the impact of professional learning on student achievement.

Table 4: Summary of Examples of Video Use in Professional Learning

	Videos to Show Other People's Practice		**Videos to Analyze Teachers' Own Practice**	
	Example 1	**Example 2**	**Example 1**	**Example 2**
Format	Synchronous	Bichronous (Synchronous and Asynchronous)	Synchronous	Bichronous (Synchronous and Asynchronous)
Task/ problem-centered	Teachers analyze a video of another teacher facilitating a mathematics discussion.	Teachers analyze a video of a teacher supporting students' exploration of a mathematics word problem.	Teachers analyze their own video with a focus on specific "look fors" or characteristics.	Teachers analyze their own video for characteristics of mathematics discussions learned in an early book study.
Activation Principle	Teachers had a common experience exploring a mathematics task in pairs during the workshop.	Teachers had an independent common experience before the professional learning by solving a word problem independently and thinking about misconceptions prior to the meeting.	The teachers analyzed and discussed the "Look fors" and characteristics of an effective mathematics discussion before watching videos with their peers.	The teachers had a common experience with a book study focused on characteristics of effective mathematics discussions.
Demonstration Principle	Teachers watch a 6 minute video of a mathematics discussion and then discuss the characteristics of the discussion.	Teachers watch a video of a teacher supporting students' exploration of a mathematics problem.	In a previous synchronous session teachers had examined characteristics of an effective mathematics discussion.	In previous asynchronous and synchronous sessions teachers participated in a book study.
Application Principle	Teachers leave the session with goals for future teaching.			
Integration Principle	Teachers will meet again in a month to reflect on their experience.			

Aligning Desired Instructional Practices and Professional Learning Activities

In all of the examples the goals of the professional learning activities were to prepare teachers to use research-based mathematics practices in their classroom. Whether the examples were in synchronous or bichronous settings the professional learning activities included were based on the premise that teachers needed to engage in meaningful and relevant tasks. This type of professional learning situated teachers as learners where they experienced and discussed specific pedagogies in order to increase the likelihood that teachers would leave the professional learning and incorporate these pedagogies in their own classroom (Darling-Hammond et al. 2007; Garet et al., 2001; Martin et al., 2019).

There is a need for professional learning facilitators to continue to begin with the end in mind by considering the question: *What are the desired instructional practices that we want teachers to use in their classroom?* Then there is a need to intentionally design learning activities that include the specific practices that they are expected to use in their classroom. In the second example where videos were used to show other teachers' practice, the teachers participated in a launch-explore-discuss learning cycle as learners before they watched a video that showed how a teacher facilitated a class discussion. As seen in the summary of the examples, Merrill's First Principles of Learning (2007) align with the framework of learner-centered professional learning (Polly & Hannafin, 2010), and are especially useful if the goal is to engage teachers in task-based learning experiences that are situated in real-life contexts and also expose them to instructional practices that align with task-based and real-life activities.

The Role of Video in Professional Learning

The use of video provided teachers with an opportunity to have a common experience (Activation Principle) or observe and analyze a desired set of teacher practices (Demonstration Principle), which helped teachers be more likely to apply these practices in their own classrooms (Application Principle). In both examples where videos were used to analyze teachers' own practices there was facilitation provided by a set of "look fors" and peer feedback (Example 1) and by the professional learning facilitator (Example 2). Both examples point to the need for video use in professional learning to be accompanied by some sort of facilitation or guidance.

Video use alone though is not sufficient as we consider future uses of video in teacher education and professional learning efforts. As indicated in earlier work, if professional learning experiences do not include follow up in teachers' classrooms, we miss opportunities to make a significant impact on participating teachers to document quality and effectiveness of practices, impact on learning (Borko et al., 2014; Polly, 2017a). Future uses of video as evidence of effective teaching will likely continue to include video to capture in situ (classroom-based) evidence as well as written reflections that ensure that teachers are able to communicate about their use of high-leverage instructional practices and reflect on the video evidence (Rich & Hannafin, 2009; Polly & Hannafin, 2011; van Es & Sherin, 2010).

Future use of video in professional learning should continue to evolve as technologies continue to develop. For example, most standard video cameras can store large amounts of video into cloud storage or another repository relatively easily enabling professional learning facilitators and teachers to have access to as many video-taped lessons as they would like. Further, there are platforms such as GoReact that allow teachers and professional learning facilitators to watch a video inside the platform and use a set of predetermined indicators and rubric levels to evaluate and/or provide feedback about teachers' use of specific practices. Research studies using these types of indicators and rubrics to evaluate videos have shown that self-evaluation increases teachers' depth of reflection and their adoption of specific instructional practices (Tripp & Rich, 2012).

The Impact of Professional Learning on Student Achievement

The goals of professional learning must include a positive impact on student achievement. Guskey (2000) proposed a framework for evaluating professional learning on five levels: 1) participants' reactions, 2) teachers' knowledge and skills, 3) teachers' application of knowledge and skills, 4) the impact on organizations and systems, and 5) student learning. Merrill's First Principles of Learning are intended to support the design of effective learning environments for all learners through task-based and real-life examples. There is a need for researchers of professional learning experiences to continue to study and examine how professional learning experiences and specific aspects of those experiences influence the various levels of Guskey's framework. More specifically, while the indelible link between professional learning and student achievement needs to be studied, it is not appropriate to make those claims without evidence about how the professional learning experience has impacted other levels of Guskey's framework, especially teachers' use of knowledge and skills.

If we consider the case of video enhancing professional learning for teachers in mathematics, future research studies need to examine the influence of both uses of videos discussed in this article where teachers are able to view and analyze other people's practice and also analyze their own practice. These studies must be intentionally designed to include multiple robust data sources including observations of professional learning, interviews of all participants, and data related to both teacher learning and student learning (Polly & Hannafin, 2010; Darling-Hammond et al., 2017).

As access to technologies and high-speed internet access becomes more common in schools there is a need to determine how to be good stewards of the technological infrastructure in a way that supports teaching and learning, which includes using technology, such as video, to improve professional learning opportunities. In mathematics education, specifically, intentional efforts must be made to develop teachers' skills and knowledge related to using mathematics tasks and problems in ways that promote productive struggle, mathematical reasoning, and include appropriate supports based on students' needs (Polly, 2017b; Polly & Holshouser, 2021). Research is needed to see how video can support those efforts related to mathematics teaching and learning.

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