

Utilizing Video to Support Planning, Enacting, and Analyzing Teaching in Preservice Science Teacher Education

by Tara Barnhart, Chapman University

Abstract

The use of video to support preservice teacher development is becoming increasingly common. However, research on teacher noticing indicates that novices need tools to focus their attention on students' disciplinary ideas. This article describes a course designed for secondary science teachers that incorporates video analysis as a core part of repeated learning cycles. Of particular interest is how well the video-analysis tasks and tools support PSTs in learning to plan, enact, analyze, and reflect on instruction. A qualitative analysis of PSTs' video annotations, lesson-analysis guides, and written reflections reveals that PSTs in the course developed a disposition towards responsive instruction and leveraged evidence of student thinking in their analyses of the effectiveness of their instruction. Lesson-analysis guides appear to be the tool PSTs relied on the most to inform their written reflections. Further investigation on how best to structure video analysis will help further refine the use of video in teacher education.

Introduction

Over a decade ago, Grossman et al. (2009) identified the need to better integrate the development of teachers' theoretical knowledge with the pedagogical skills needed in everyday teaching. They proposed three core pedagogies to develop professional knowledge and skill in teacher education: representations, decomposition, and approximations of practice. Representations of practice establish a vision of what is possible through observations as well as artifacts of teaching such as recordings and student work. Providing a representation of responsive teaching practice is particularly important because many PSTs may not have experienced this type of instruction as a learner and may not reliably encounter it during fieldwork. Decomposition of practice breaks down the complex practice of teaching into its component skills. Decomposition permits a focus on developing competence in these constituent practices in manageable pieces so they can later be layered together in increasingly complex and authentic approximations of practice.

In an extension of this work, McDonald et al. (2013) proposed the use of learning cycles in teacher preparation: learning about a practice, planning and rehearsing the practice, enacting the practice, and analyzing the enactment of that practice. This cycle describes methods by which representations, decomposition, and approximations may be achieved across a variety of teacher preparation settings. By articulating a general cycle that could be

utilized across a variety of programs, they aspired to provide a common language to study teacher education while also allowing for the customization of pedagogies and practices particular to each discipline. The hope was to provide “a framework for aggregating pedagogical knowledge and tools” and identify core practices that bridge K–12 teaching and teacher education pedagogies (McDonald et al., 2013, p. 385).

Simultaneously, a different line of teacher professional development scholarship has advanced an approach broadly defined as responsive teaching. Responsive teaching is characterized by “the depth to which students’ ideas are pursued and the extent to which teachers’ responses require *students* to do the ensuing intellectual work” (Richards, 2013, p. 18–19). In science education, specifically, this approach entails a shift to more student-centered, inquiry-based instructional practices that promote students’ making sense of a scientific phenomenon (Windschitl et al., 2018).

Responsive science teaching requires that teachers design opportunities to elicit and work with students’ ideas about meaningful science phenomena and make that thinking visible (Hammer & van Zee, 2006; Kang et al., 2014; Windschitl et al., 2012). During the enactment of instruction, teachers must *notice* students’ ideas—attend closely to the substance of students’ ideas and engage in making sense of what these ideas might mean about students’ science understanding (van Es & Sherin, 2002).

Video has proven to be a useful tool for developing PST noticing of student thinking (Groth et al., 2021; Johnson & Mawyer, 2019). Because video footage can be slowed down and viewed multiple times, it can be used both as a representation of practice and as a way to experience and decompose the complexity of teaching without being overwhelmed (Miller & Zhou, 2007). Video has been shown to greatly enhance analysis of and reflection on instruction by increasing the focus on students and their thinking (Luna & Sherin, 2017; Ulusoy & Çakıroğlu, 2018).

However, it is not a given that teachers will automatically focus on student thinking while viewing video (Blomberg et al., 2013) or when simply asked to do so (Jacobs et al., 2010). Consideration must be given to how the video is selected and framed and what tools are used to support analysis of the video (Kang & van Es, 2018; van Es et al., 2015; van Es et al., 2020). Of particular importance is the use of *callouts* (van Es & Sherin, 2002) as evidence to support interpretations of students’ thinking. Callouts provide indications to teacher educators about what participants mark as noteworthy and also serve to keep teachers’ claims about instruction focused on evidence (van Es & Sherin, 2008).

The purpose of developing PSTs’ noticing of student ideas is so they will then respond to what they notice in ways that advance students’ understanding of science concepts and practices (Robertson et al., 2016). However, studies that look specifically at responding in relation to noticing indicate that although notable progress can be made in supporting sophisticated noticing, responding to what one notices is very challenging for PSTs (Barnhart

& van Es, 2015; Luna & Selmer, 2021; Schäfer & Seidel, 2015). Making in-the-moment decisions about what to do with students' ideas is highly contextual and is often subject to competing instructional priorities (Richards & Robertson, 2016). Awareness of one's broader instructional purposes is an important touchstone that guides teachers when they make decisions about whose idea to take up, whether or not to press for canonical correctness, or when to shift from eliciting more ideas to pursuing the exploration of one idea (Coles, 2013; Russ & Luna, 2013). Therefore, noticing work with PSTs should also cultivate a disposition that values students and their ideas as a central component of teaching and planning (Levin et al., 2013; Luna & Sherin, 2017; Richards et al., 2015).

Course Design

With these elements in mind, I developed a preservice science teaching methods course design that employed multiple cycles of planning, enacting, analyzing, and reflecting on collaboratively planned science lessons. The goals of the design are to hone PST noticing of science students' ideas as resources for planning and enacting responsive teaching; to provide repeated opportunities to observe, decompose, and enact approximations of responsive teaching; and to develop a disposition for relying on evidence of student learning in their analyses of teaching. This course is the second of a two-semester-long science methods sequence for middle school and high school PSTs that runs concurrently with a fieldwork placement. At the beginning of the first-semester science methods course, PSTs are divided into groups of two or three by subject area. PSTs remain in their groups through the second semester. In these groups, they learn about the *Next Generation Science Standards* (NGSS Lead States, 2013) and collaboratively design an instructional unit organized around an anchoring phenomenon using the Ambitious Science Teaching Framework, which includes: planning for engagement with big science ideas, eliciting students' ideas, supporting ongoing changes in students' thinking, and drawing together evidence-based explanations (Windschitl et al., 2018). During the second-semester science methods course, PSTs begin to explore video examples of what responsive teaching looks like using tools to promote a student-centered, interpretive lens.

In the first phase of each cycle, PSTs participate in a lesson as learners. The purpose of this lesson is to model what responsive instruction might look like and to provide insights into how students might experience the task. Some example activities include composing an explanatory model of how a steam-filled can might collapse when quickly plunged into a cold-water bath and participating in a simulation of the water cycle. We then debrief their experience, paying particular attention to the amount of choice and voice they had in their learning.

We then build upon the idea of seeking evidence of building towards mechanistic explanations by watching published videos of classroom interactions from Tools for Ambitious Science Teaching (<http://ambitiousscience Teaching.org>) and *Seeing the Science in Children's Thinking* (Hammer & van Zee, 2006). The videos provide another representation

of responsive teaching and serve as a source of evidence to analyze the relationship between teaching and student thinking (Kang & van Es, 2018). I selected a video analogous to the lesson they just experienced—a segment from the Eliciting Students' Ideas section from the Gas Laws lesson (Tools for Ambitious Science Teaching, <https://ambitioussciencelearning.org/high-school-%E2%80%A2-gas-laws-%E2%80%A2-legacy-series/>) as analog to the can-crush phenomenon or the Chaos in the Corridor video from *Seeing the Science in Children's Thinking* (Hammer & van Zee, 2006) as analog to the water cycle simulation. The Tools for Ambitious Science Teaching (<http://ambitioussciencelearning.org>) videos are particularly relevant because they feature students who are engaging in complex thinking and are demographically similar to the students PSTs work with during their fieldwork placement (Zhang et al., 2015).

To support PSTs in identifying and interpreting noteworthy moments of student thinking in the videos, I provide a transcript of the videos, and we use the Learning to Notice Framework (van Es & Sherin, 2008). When a PST raises an interesting student idea, I direct them to the transcript so the class can closely examine that moment and attempt to interpret the student's scientific understanding and what experiences the student might be drawing on to inform their ideas. The focus at this time is on describing and interpreting students' thinking rather than evaluating its correctness (van Es & Sherin, 2008).

In a second viewing of the videos, we identify teacher moves that supported either eliciting, working with, or supporting changes in students' thinking (Tools for Ambitious Science Teaching). I do not take up discussions of teacher moves in the first viewing to emphasize that the purpose of teaching is not to enact a list of teaching moves but to support the increasing sophistication of students' thinking. Again, we rely on the transcript to describe and interpret what might have motivated a particular teaching move and what student thinking resulted from the move. I also use the transcript to redirect PSTs back to the evidence in the clip to maintain a focus on how teacher and student talk are interrelated in the shared video artifact (van Es et al., 2014) and limit less productive anecdotal talk (Barnhart & van Es, 2020).

In the next phase, each group codesigns a lesson using the Ambitious Science Teaching Framework that at least one member of the group can enact and video record in their fieldwork placement. Ideally, the group would design a lesson analogous to the lesson type they just experienced and analyzed, but I do not insist on mirroring the model lesson. Based on the experience of many of my previous PSTs, flexibility in planning is important. Many PSTs experience resistance in being able to enact a lesson that significantly deviates from their mentor's routine during fieldwork. Another complication is timing: Will the lesson type fit with where the PSTs' students are in a unit of instruction? Having multiple classrooms available to the group and fewer constraints increases the likelihood that someone in the group will be able to enact the designed lesson.

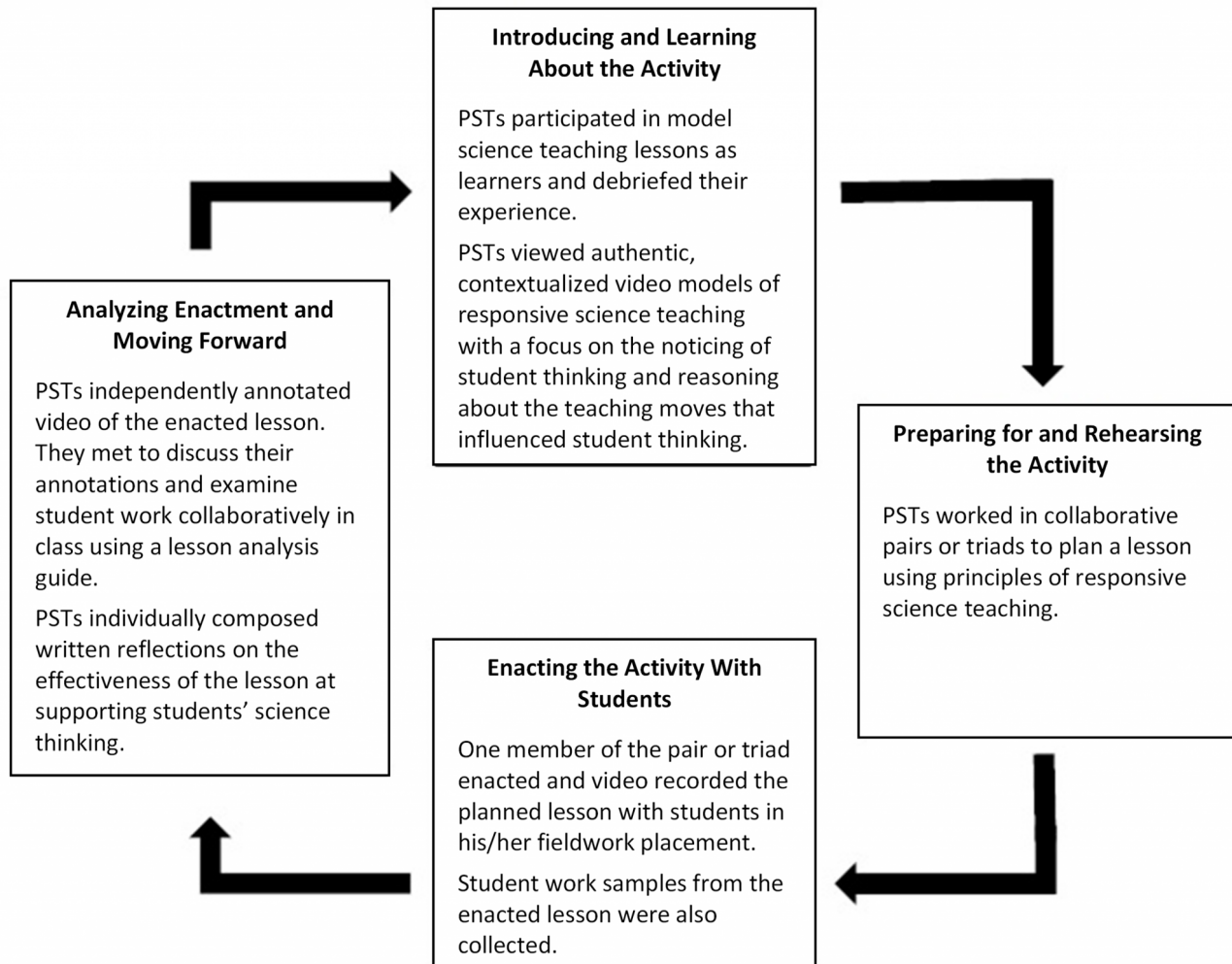
After the lesson is enacted and recorded, each member of the group individually annotates their group's video using a video annotation software. Having each PST annotate individually allows them to come to class with their own impressions of the lesson and provides an opportunity for them to practice the close attention and interpretation of student thinking that we had engaged in with the model lesson videos. During class, each group meets to discuss their video annotations and student work samples, if available, and notes their ideas on a lesson-analysis guide (see Appendix). Recording what the group notices on the analysis guide allows the PSTs to capture and organize their impressions of the lesson and reinforces connections between instructional choices and student thinking. The guide frames lesson analysis around specific evidence of student learning by positioning the goal of the lesson and student evidence in the first two columns and placing instructional contributions and adjustments in the last two columns (Santagata et al., 2007).

In the last phase of the cycle, each PST uses the lesson-analysis guide to compose a lesson reflection in which they are prompted to consider evidence about the lessons' effectiveness, something that surprised them, and something that they would do going forward. The act of writing their analysis of the lesson provides evidence of their evolving development as thoughtful and purposeful designers, promotes a disposition towards relying on evidence of student thinking to inform instructional decisions, encourages taking instructional action based on their analysis (Dewey, 1933; Schön, 1983), and reveals aspects of their teaching practice that might need additional support during our class time.

This four-phase cycle repeats three times over the 15-week course (see Figure 1). In general, one class meeting is spent participating in a lesson and watching an analogous video, and the following class meeting is spent on planning a sequence. Half a class meeting during the following 2 weeks is dedicated to collaborative lesson analysis. In between cycles, I highlight examples from PST reflections that made excellent use of video evidence to support claims about lesson effectiveness in terms of student learning. I also highlight examples that made claims about instruction or learning without the use of evidence, and we discuss potential evidence that the author could include to support that claim. Thus, PSTs have multiple opportunities to collaboratively design, enact, analyze, and discuss instruction with feedback from me.

Figure 1

The Four-Step Cycle Enacted in the Second Semester Science Methods Course



Note. The four-step cycle used here was adapted from McDonald et al.'s (2013) learning cycle (see Figure 1 on p. 382).

Analysis of the Design

To understand how effective the design was in focusing PSTs' attention on students' ideas, I analyzed their video annotations, lesson-analysis guides, and written lesson reflections from the three cycles. Every group planned and was able to implement their designed lesson in their fieldwork placement. Not every group was able to video record; however, all the PSTs (11) were able to collect student work. Each group member analyzed and reflected on their group's lesson and submitted a written reflection for all three cycles with one exception (Group 1's third lesson). Table 1 details the lessons designed, enacted, and analyzed by each group.

Table 1*Lessons Designed, Enacted, and Analyzed by Each Group*

Lesson	Enacted by	Analyzed by
Group 1: Bob & Mary (high school biology)		
Predator–prey relationships	Mary	Mary & Bob
Bacterial classification	Bob	Mary & Bob
Surviving the zombie apocalypse (what do living things need to survive?)	Mary	Bob ^a
Group 2: David & Kerry (high school biology)		
Sharks and whales divergent and convergent evolution	David	David & Kerry
Genetic variation and meiosis	Kerry	David & Kerry
Factors influencing photosynthesis	David	David & Kerry
Group 3: Jane & Marta (middle school physical science)		
What are the phases of the moon?	Jane & Marta	Jane & Marta
Where does energy come from?	Marta	Jane & Marta
How do materials affect sound transmission?	Jane & Marta	Jane & Marta
Group 4: James, Phong, & Nancy (high school biology)		
Cycling of matter in an ecosystem	James	James, Phong, & Nancy
Genetic variety in puppies	Phong	James, Phong, & Nancy
Virus transmission	Nancy	James, Phong, & Nancy
Group 5: Lourdes & Mateo (high school chemistry)		
Predict the products and type of chemical reaction	Lourdes	Lourdes & Mateo
How does a color-changing (temperature-sensitive) mug work?	Mateo	Lourdes & Mateo
Rates of radioactive decay	Lourdes	Lourdes & Mateo

^a Mary did not complete the third written analysis and reflection due to a family emergency.

As seen in Table 2, PSTs most frequently commented on students' ideas themselves (44% of all comments) or instructional moves intended to elicit or work with students' ideas (21% of all comments). PSTs also paid attention to students' lesson activity directly (7% describing and interpreting) and describing teaching moves related to students' activity (7%). Twenty percent of all comments were related to classroom management despite this not being the primary focus of any tool (video annotations, analysis guide, or written reflection).

To get a sense of how what PSTs noticed was used to inform instruction, I looked across the video annotations, lesson-analysis guides, and written reflections. Tracking ideas across the data sources revealed that around half of the describing and interpreting student idea annotations came from PSTs' written reflections. Group members often mentioned the same

student idea in their individual reflections and referenced how their in-class group made sense of the student idea. Ideas not included in individual video annotations did appear in the collaboratively created lesson-analysis guides. This is an indication that the video annotation tool and the analysis guide were useful in promoting the use of specific moments of student thinking to inform instruction. However, two PSTs did not use evidence from the video or guide to inform their reflections and instead included vague accounts of the lesson and general recommendations for future action (Levin & Richards, 2011).

Table 2

Frequency of Codes Across Video, Tools, and Written Reflections

	Describing & interpreting student ideas	Eliciting & working with student ideas	Describing & interpreting student activity	Describing moves supporting student activity	Describing classroom management	Other	Total
Video annotations	18	12	0	3	8	0	41
Lesson-analysis guides	88	54	4	6	48	2	202
Written reflections	95	29	29	25	35	1	214
Total	201	95	33	34	91	3	457

An example of an idea being noticed in the video and tracing through the analysis tool and into the written reflection was from James, Phong, and Nancy's lesson about genetic recombination in a litter of puppies. Students were charged with developing an explanation for why puppies looked similar and different from their parents. In their lesson video, a student indicated that a puppy looked more like the father than the mother because the father contributed "more DNA." James added the annotation "More DNA? What do you mean by more?" This interaction was elaborated on in the analysis guide and included a direct quote of the student's response that because the father was a larger breed than the mother, his DNA was "larger." All three group members referenced this particular student idea in their written reflection on the lesson, noting that students were attempting to draw on their everyday experiences to make sense of heredity. James wrote:

The student said, "the puppy looks more like the dad because he has more genes." A lot of students have this alternative conception, and it probably stems from a basic understanding that when you mix things, you will see whatever there is more of more often. For example, if I mixed 100 skittles with 10 M&M's, the bowl will look more like a bowl of skittles. The student tried to apply that same basic understanding to heredity.

James then critiqued the use of a leading question to "correct" this idea at this point in the instructional sequence, noting that this was an "eliciting ideas" lesson, and proposed a less evaluative teacher move. His two groupmates also pointed out this student idea but did not

recommend an instructional action in response.

More student idea callouts were noted on the analysis guide that PSTs completed together in class than were made using the video annotation tool itself at home (see Table 2).

Sometimes an observation grounded in a student-work sample rather than the video was documented in the analysis guide. The number of specific student idea callouts made using the analysis guide ranged from three to eight across the PSTs. Often one or two of these specific ideas would be taken up in each PSTs' written reflection in response.

For example, in Mary and Bob's lesson about bacterial classification, Mary noted several student responses in her video annotations. Two responses were about students' confusion about why water and carbon dioxide were not "organic" molecules, two were about students making connections between everyday language and the Latin and Greek roots used in bacterial nomenclature, and one was about the use of stains to classify bacteria. In their analysis guide, Mary and Bob noted students' ideas about the components of cell membranes in addition to the video notes about organic molecules and students' ability to classify bacteria. However, in her written reflection, Mary only mentioned the student confusion about what it means in chemistry to be an "organic" molecule: "This demonstrates a clear mix up between what organic molecules are and the elements that compose them. This was never settled for the student, so he may need additional explanation to be able to separate the two." She noted it as a moment of student thinking and evaluated it as a potential issue that could complicate further instruction.

In addition to noticing students' ideas, PSTs also considered those ideas when reflecting on their lesson design. When writing about the effectiveness of their instruction or what they might do if they were to teach the same lesson again, PSTs frequently cited students' participation and engagement as measures of success. Novice attention to student engagement and participation is typical (Star et al., 2011). What is noteworthy is that PSTs defined participation and engagement as how frequently students contributed to whole-group or small-group discussions of science ideas with classmates not just being "on task." Several PSTs specifically mentioned the importance of a relevant and demanding phenomenon or problem. In all but two of the written reflections, the proposed next moves were related to the student ideas noted in the analysis guide. The two unrelated recommendations involved adjustments to the activity to increase students' hands-on access.

More commonly, PSTs proposed adjustments to increase access to their students' complex thinking. Some adjustments addressed changing the structure of the lesson to make it more rigorous. For example, Mary mentioned that the bacterial classification lesson was too didactic and should be reorganized to permit students to apply principles of taxonomy as a scientific practice rather than memorize how to use this particular taxonomic key. Marta felt that the opening question in her electricity lesson was too restrictive and did not push students' thinking enough to provide a variety of answers. In both cases, Mary and Marta noted that their students' engagement in the lesson suffered. In a similar vein, two PSTs,

(David and Nancy) noted that their opening questions were too broad or were not, in David's words, "sufficiently rich" to generate enough discussion. Nancy noted that the structure of the lab-generated data was too unwieldy for students to "identify meaningful trends." By making an adjustment between class periods, she noted that students had a livelier, evidence-based discussion about disease transmission in subsequent periods. Mateo expressed concern that the failure to provide clear parameters about the "system" students were attempting to explain led to "inconsistencies" and "inaccuracies" in their understanding of thermodynamics. Several PSTs noted (Mary, Nancy, David, Kerry, Mateo, Jane, & Marta) that their students needed more time to elaborate on their initial ideas during their attempts to construct explanatory models. This would permit the teacher to "get a better understanding of students' prior understanding of genetics as well as alternate conceptions that students have" and allow for students to "see different answers from their peers because it forces them to rethink and justify their own answers." The purpose of these adjustments demonstrates that the PSTs valued access to student ideas both to inform their future instruction and to serve as resources to push other students' thinking.

Conclusion and Implications

This course had three goals: to focus PST attention on students' ideas as a central part of planning for and enacting responsive teaching, to provide repeated opportunities to establish representations and decompositions of responsive practice and to enact approximations of practice, and to promote a disposition for relying on evidence of student learning in their analyses of teaching. Evidence that PSTs in this course attended and responded to students and their thinking and used access to students' ideas as indicators for lesson "success" suggests an ambitious conception of what their students can do as well as a recognition of the teachers' role to foreground students' disciplinary ideas (Robertson et al., 2016). Given the importance of dispositions in driving instructional choices, the PSTs' attention to students' ideas and consideration of students' ideas as central to lesson success is noteworthy.

The intended purpose of individually annotating videos prior to group discussion was to set up a richer, evidence-based examination of student thinking stimulated by the lesson (van Es & Sherin, 2008). This design choice appears to have been effective at maintaining a focus on student thinking when analyzing the lesson because many of these video callouts were taken up in the written reflections and used to inform future instructional responses. An even more important design choice appears to have been the opportunity to discuss callouts with classmates because the notes from the collectively constructed analysis guide were more numerous and more likely to end up in PSTs' written reflections. A comparison of the types of conversations PSTs have with and without the preceding individual callout work could yield further insights into the value of this particular activity. Historically, PSTs complained the most about completing individual annotations of everyone's lesson before class. This iteration of the design reduced that requirement to just analyzing their own group's lessons. Anecdotally, students reported that the source of their resistance to this activity was the time it took rather than a lack of perceived value in the activity. More recently, I provided time during class to

annotate every lesson, but the tradeoff was that we were able to complete fewer lesson study cycles. That decision, in turn, leads to another design tension—opportunities to practice all phases of instruction.

These PSTs viewed their role as elicitors of ideas in lessons that begin instructional sequences, but how PSTs view their role as they move with students through instructional sequences is less clear. PSTs overwhelmingly chose to analyze lessons early in the instructional sequence to analyze. Launching lessons in which the teachers' role is to elicit and interpret students' initial ideas are important because they appear to set a high-water mark for cognitive complexity in an instructional sequence (Kang et al., 2016). Such lessons are also less demanding than lessons in which students' ideas are taken up, connected to scientific principles, or acted upon to inform further in-class inquiries (Jacobs et al., 2010; Robertson et al., 2016). Instruction that features efforts to make students' ideas visible is probably a reasonable place to start practicing the integration of noticing skills needed to enact responsive teaching but is not enough to achieve the learning goals defined by the *Next Generation Science Standards* (NGSS Lead States, 2013).

Further, despite the course's focus on interpreting rather than evaluating student thinking over multiple cycles, PSTs often used evaluative language when describing students' ideas and strove to pursue canonical correctness. This was particularly the case with lessons that tended to be more didactic and focused on the transmission of cannon (e.g., bacterial classification) rather than the development of rigorous scientific reasoning (e.g., how viruses spread). It could very well be the case that analyzing lessons that lack certain affordances is incompatible with the development of responsive teaching (Kang & van Es, 2018).

Given the frequency with which groupmates took up the annotations of others during their video conversations to inform their written lesson reflections, requiring one lesson type from each phase of the ambitious science teaching cycle and broadening the discussion of videos to include perhaps one other group beyond one's own in each cycle may provide more opportunities to approximate all phases of responsive teaching practice. Collaborative, tool-supported video analysis is a useful tool for representing, decomposing, and studying approximations of responsive teaching practice. As video use becomes even more pervasive in teacher development programs, attention to the balancing of design principles and the constraints of the teacher education context is important for the field to document and study.

Supplemental Files

[Appendix-Barnhart-2022.docx](#)

References

Barnhart, T., & van Es, E. (2015). Studying teacher noticing: Examining the relationship among pre-service science teachers' ability to attend, analyze and respond to student thinking. *Teaching and Teacher Education*, 45, 83–93.
<https://doi.org/10.1016/j.tate.2014.09.005>

Barnhart, T. & van Es, E. (2020). Developing a critical discourse about teaching and learning: The case of a secondary science video club. *Journal of Science Teacher Education*, 31(5), 491-514.

Blomberg, G., Renkl, A., Sherin, M. G., Borko, H., & Seidel, T. (2013). Five research-based heuristics for using video in pre-service teacher education. *Journal for Educational Research Online*, 5(1), 90–114. <https://www.waxmann.com/artikelART102716>

Coles, A. (2013). Using video for professional development: The role of the discussion facilitator. *Journal of Mathematics Teacher Education*, 16(3), 165–184.
<https://doi.org/10.1007/s10857-012-9225-0>

Dewey, J. (1933). *How we think: A restatement of the relation of reflective thinking to the educative process*. D. C. Heath and Company.

Grossman, P., Hammerness, K., & McDonald, M. (2009). Redefining teaching, re-imagining teacher education. *Teachers and Teaching: Theory and Practice*, 15(2), 273–289.
<https://doi.org/10.1080/13540600902875340>

Groth, R. E., Bergner, J. A., Weaver, S. D., & Follmer, D. J. (2021). Virtual tools and protocols to support collaborative reflection during lesson study. *Innovations in Science Teacher Education*, 6(4). <https://innovations.theaste.org/virtual-tools-and-protocols-to-support-collaborative-reflection-during-lesson-study/>

Hammer, D., & van Zee, E. (2006). *Seeing the science in children's thinking: Case studies of student inquiry in physical science*. Heinemann.

Jacobs, V. R., Lamb, L. L. C., & Philipp, R. A. (2010). Professional noticing of children's mathematical thinking. *Journal for Research in Mathematics Education*, 41(2), 169–202.
<https://doi.org/10.5951/jresmetheduc.41.2.0169>

Johnson, H. J., & Mawyer, K. K. N. (2019). Teacher candidate tool-supported video analysis of students' science thinking. *Journal of Science Teacher Education*, 30(5), 528–547.
<https://doi.org/10.1080/1046560X.2019.1588630>

Kang, H., Thompson, J., & Windschitl, M. (2014). Creating opportunities for students to show what they know: The role of scaffolding in assessment tasks. *Science Education*, 98(4), 674–704. <https://doi.org/10.1002/sce.21123>

- Kang, H., & van Es, E. A. (2018). Articulating design principles for productive use of video in perservice education. *Journal of Teacher Education*, 70(3), 237–250.
<https://doi.org/10.1177/0022487118778549>
- Kang, H., Windschitl, M., Stroupe, D., & Thompson, J. (2016). Designing, launching, and implementing high quality learning opportunities for students that advance scientific thinking. *Journal of Research in Science Teaching*, 53(9), 1316–1340.
<https://doi.org/10.1002/tea.21329>
- Levin, D., Hammer, D., Elby, A., & Coffey, J. (2013). *Becoming a responsive science teacher: Focusing on student thinking in secondary science*. NSTA Press.
- Levin, D. M., & Richards, J. (2011). Learning to attend to the substance of students' thinking in science. *Science Educator*, 20(2), 1–11.
- Luna, M., & Selmer, S. (2021). Examining the responding component of teacher noticing: A case of one teacher's pedagogical responses to students' thinking in classroom artifacts. *Journal of Teacher Education*, 72(5), 579–593. <https://doi.org/10.1177/00224871211015980>
- Luna, M. J., & Sherin, M. G. (2017). Using a video club design to promote teacher attention to students' ideas in science. *Teaching and Teacher Education*, 66, 282–294.
<https://doi.org/10.1016/j.tate.2017.04.019>
- McDonald, M., Kazemi, E., & Kavanagh, S. S. (2013). Core practices and pedagogies of teacher education: A call for a common language and collective activity. *Journal of Teacher Education*, 64(5), 378–386. <https://doi.org/10.1177/0022487113493807>
- Miller, K., & Zhou, X. (2007). Learning from classroom video: What makes it compelling and what makes it hard. In R. Goldman, R. Pea, B. Barron, & S. J. Derry (Eds.), *Video research in the learning sciences* (pp. 321–334). Lawrence Earlbaum Associates.
- NGSS Lead States. (2013). *Next generation science standards: For states, by states*. National Academies Press. <https://doi.org/10.17226/18290>
- Richards, J. (2013). *Exploring what stabilizes teachers' attention and responsiveness to the substance of students' scientific thinking in the classroom* (UMI No. 3599547) [Doctoral dissertation, University of Maryland, College Park]. ProQuest Dissertations and Theses Global.
- Richards, J., Elby, A., & Gupta, A. (2015). *Incorporating disciplinary practices into characterizations of progress in responsive teaching*. arXiv.org.
<https://arxiv.org/abs/1502.04420>

Richards, J., & Robertson, A. D. (2016). A review of the research on responsive teaching in science and mathematics. In A. D. Robertson, R. E. Scherr, & D. Hammer (Eds.), *Responsive teaching in science and mathematics* (pp. 36–55). Routledge.

Robertson, A. D., Atkins, L. J., Levin, D. M., & Richards, J. (2016). What is responsive teaching? In A. D. Robertson, R. E. Scherr, & D. Hammer (Eds.), *Responsive teaching in science and mathematics* (pp. 1–35). Routledge.

Russ, R. S., & Luna, M. J. (2013). Inferring teacher epistemological framing from local patterns in teacher noticing. *Journal of Research in Science Teaching*, 50(3), 284–314. <https://doi.org/10.1002/tea.21063>

Santagata, R., Zannoni, C., & Stigler, J. W. (2007). The role of lesson analysis in pre-service teacher education: An empirical investigation of teacher learning from a virtual video-based field experience. *Journal of Mathematics Teacher Education*, 10(2), 123–140. <https://doi.org/10.1007/s10857-007-9029-9>

Schäfer, S., & Seidel, T. (2015). Noticing and reasoning of teaching and learning components by pre-service teachers. *Journal for Educational Research Online*, 7(2), 34–58. <https://www.waxmann.com/artikelART102833>

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. Basic Books.

Star, J. R., Lynch, K., & Perova, N. (2011). Using video to improve pre-service mathematics teachers' abilities to attend to classroom features: A replication study. In M. G. Sherin, V. R. Jacobs, & R. A. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (pp. 117–133). Routledge.

Tools for Ambitious Science Teaching. (2021, November 5). Retrieved from <https://ambitioussciencelearning.org/>

Ulusoy, F., & Çakıroğlu, E. (2018). Using video cases and small-scale research projects to explore prospective mathematics teachers' noticing of student thinking. *Eurasia Journal of Mathematics, Science and Technology Education*, 14(11), Article em1571. <https://doi.org/10.29333/ejmste/92020>

van Es, E. A., & Sherin, M. G. (2002). Learning to notice: Scaffolding new teachers' interpretations of classroom interactions. *Journal of Technology and Teacher Education*, 10(4), 571–596.

van Es, E. A., & Sherin, M. G. (2008). Mathematics teachers' "learning to notice" in the context of a video club. *Teaching and Teacher Education*, 24(2), 244–276. <https://doi.org/10.1016/j.tate.2006.11.005>

- van Es, E. A., Stockero, S. L., Sherin, M. G., Van Zoest, L. R., & Dyer, E. (2015). Making the most of teacher self-captured video. *Mathematics Teacher Educator*, 4(1), 6–19.
<https://doi.org/10.5951/mathteaceduc.4.1.0006>
- van Es, E. A., Tekkumru-Kisa, M., & Seago, N. (2020). Leveraging the power of video for teacher learning: A design framework for mathematics teacher educators. In S. Llinares & O. Chapman (Eds.), *International handbook of mathematics teacher education: Tools and processes in mathematics teacher education* (2nd ed., Vol. 2, pp. 23–54). Brill.
https://doi.org/10.1163/9789004418967_002
- van Es, E. A., Tunney, J., Goldsmith, L. T., & Seago, N. (2014). A framework for the facilitation of teachers' analysis of video. *Journal of Teacher Education*, 65(4), 340–356.
<https://doi.org/10.1177/0022487114534266>
- Windschitl, M., Thompson, J., & Braaten, M. (2018). *Ambitious science teaching*. Harvard Education Press.
- Windschitl, M., Thompson, J., Braaten, M., & Stroupe, D. (2012). Proposing a core set of instructional practices and tools for teachers of science. *Science Education*, 96(5), 878–903.
<https://doi.org/10.1002/sce.21027>
- Zhang, M., Koehler, M., & Lundeborg, M. (2015). Affordances and challenges of different types of video for teachers' professional development. In B. Calandra & P. J. Rich (Eds.), *Digital video for teacher education: Research and practice* (pp.147–163). Routledge.