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PK 12

Evaluating Videos for Flipped Instruction

A framework describes the benefits of including interactive features and considering options beyond lecturing.

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Given the growing amount of online video content, it is unsurprising that teachers are increasingly exploring flipped instruction (Smith 2014). Flipped instruction involves using videos or other multimedia as homework assignments instead of the more typical problem sets. By presenting content outside of class, teachers can use in-class time in potentially beneficial ways, such as by providing individualized support while students work (Bergman and Sams 2012) or offering extended opportunities for collaboration and discussion (de Araujo, Otten, and Birisci 2017a).

Although much of the potential for innovation comes from the use of class time, interviews with mathematics teachers reveal that they spend a great deal of time and energy on the videos for their flipped lessons (de Araujo, Otten, and Birisci 2017a). Whether discovering ready-to-use videos or creating their own, teachers can find the process daunting. And creating a video lecture is not the same as lecturing in front of a class. For instance, although some in-class lectures might be interactive, incorporating interactivity into a video lecture might require extra effort and technological tools.

To aid with the process of selecting or creating videos for flipped instruction, we present a research-based framework of key video characteristics to consider. Some of the characteristics (e.g., mathematical quality) may be obvious but are important nonetheless. Other characteristics (e.g., multimedia design, interactivity, videos that set up an in-class investigation) are often overlooked (de Araujo, Otten, and Birisci 2017b) but may be especially important for those who want to use flipped instruction in more innovative ways.

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LECTURE VIDEOS

We distinguish between two types of videos that have different purposes in flipped lessons. The first type we discuss is by far the most common—*lecture videos*. These are instructional videos primarily designed to deliver information to viewers or to demonstrate how to solve certain kinds of problems. We then discuss the other, much more rarely used type of video—*setup videos*. In both cases, we use the term *video* to refer broadly to whatever form of multimedia was assigned as the homework within the flipped instruction.

Mathematical Quality

Because lecture videos present material, the fundamental desire for that material to be of high mathematical quality is understandable. To assess the mathematical quality, we drew on the Mathematical Quality of Instruction (MQI) instrument (Ball, Bass, and Hill 2011). The MQI, however, was designed for in-class instruction, so we adapted it by focusing on specific subcategories relevant to lecture videos: (1) the richness and development of the mathematics; (2) language; and (3) unmitigated mathematical errors. A video ranks highly on the first subcategory if mathematical ideas are motivated intellectually, justified conceptually, and represented meaningfully. The second subcategory involves assessing whether the language is not only precise but also appropriate for the learners. The third subcategory allows for errors in the presentation of the mathematics, but high-quality videos mitigate those errors by discussing them purposefully or by at least acknowledging the mistake and correcting it.

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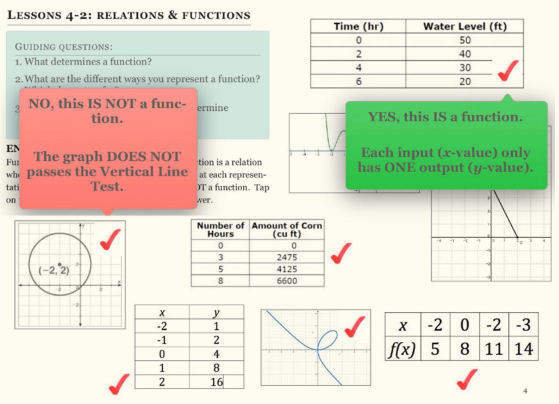
Fig. 1



Ms. Maynard (2015) incorporated multiple representations into her iBook section. Note that the check marks do not indicate functions; they are clickable components that reveal whether the relation is a function.

To illustrate these considerations for mathematical quality, we analyze a video example that introduces the idea of a mathematical function, which is, according to the Common Core State Standards for Mathematics, a "critical area" of focus in grade 8 (NGA Center and CCSSO 2010, p. 52; see also cluster 8.F). This exemplar was created by a middle school mathematics teacher, who we refer to as Ms. Maynard, and she made these multimedia resources for use with her own students. Due to research restrictions, we cannot post her full resource, but we include descriptions and screenshots below. The "video" is actually an iBook lesson she created, comprising text, images, and video.

Maynard incorporated richness and development of the mathematics by paying careful attention to the key idea that each input in a function has a unique output. In text, she wrote that a "function is a relation where every input has exactly ONE output," which builds on the previous concept of relation. In her video accompanying the text, she also stated aloud and wrote, "For every x-value, there is only 1 y-value." Then she displayed a variety of representations of both functions and nonfunctions (see figure 1). Students could interact with the examples and nonexamples by clicking on the checkmarks to bring up an explanation (visit https://youtu.be/YWjjRaYzQtw to see these features in action). The graphs use a procedural reliance on the vertical line test, but the embedded video also contained mapping diagrams, tables, and sets of ordered pairs, and Maynard described in each instance how to think about the uniqueness of the output.

By contrast, a lecture video might fail to meet the criteria for richness and development of the mathematical ideas if it provides examples of functions and function notation but does not contain the central idea that each input has a uniquely determined output. To be more specific, consider the following example from a Khan Academy lecture video. As part of an introduction to the function concept, a piecewise function was defined where $f(x)$ equals x^2 when x is even and equals $x + 5$ when x is odd. However, even and odd numbers being mutually exclusive was not mentioned, which is what guarantees this is actually a function. Furthermore, only symbolic representations were used, and the mathematical structure of the function was not emphasized systematically. In particular, when evaluating $f(2)$, the author wrote $f(2) = 4$ rather than $f(2) = 2^2$, and when evaluating $f(3)$, wrote $f(3) = 8$ rather than $f(3) = 3 + 5$. Replacing x with the respective values would have more clearly revealed the structure of the function.

Although Maynard's lecture video exemplifies some features of mathematical quality, Maynard's language lacked precision at one point. She used a metaphor of "dancing at a ball" to describe the defining feature of a function:

> For every one person, you can only dance with one more person at the dance. If you decided to dance with two people, it is not going to be pretty by the end of the night.

This parable seems appropriate for students in terms of connecting to their experiences (see the Personalization principle below), but it was not mathematically sound because it seems to require functions be one-to-one (i.e., two inputs associated with the same output would cause the same personal drama at the dance as two outputs associated with the same input).

An example of more troublesome uses of language would be a video referring to inputs of a function being *changed* into outputs or describing a function as *munching* the input to produce the output. This language is problematic because inputs do not actually change into outputs but rather are associated with outputs. In other words, x-values do not *become* y-values, just as time does not magically *become* a distance in a distance-time function; rather, the function captures the relationship between distance and time as they vary together. Talking about functions as if *x* changes into *y* emphasizes a procedural mindset of performing operations on the input value; whereas talking about functions as associations can set the stage for covariational thinking, which is central to algebraic reasoning overall (Oehrtman, Carlson, and Thompson 2008). Troublesome language in the elementary grades might be, for instance, a video that introduces fractions using "out of" language (e.g., Everyone gets one out of the four parts of the cake), which is a phrasing that sometimes impedes fraction understanding (Karp, Bush, and Dougherty 2014). Thus, when choosing or creating a lecture video to use with students, carefully consider the language used and how it may reveal or obscure the underlying mathematics.

Multimedia Design

Although the mathematical quality of lecture videos is important, the mathematical ideas must be conveyed via multimedia design. To assess the quality of design, we drew on Clark and Mayer's (2008) principles of digital material design:

- The Multimedia principle (judiciously select and add graphics to text)
- The Contiguity principle (place relevant text near graphics)
- The Modality principle (explain graphics with audio)
- The Redundancy principle (include audio that does more than simply read aloud written text)
- The Coherence principle (use only pertinent graphics and audio)
- The Personalization principle (use a conversational tone when possible).

These principles have been linked consistently to students' learning from videos. To illustrate these principles in the context of middle school mathematics, we return to Maynard's video.

Maynard's video met all six principles of multimedia design. She displayed relevant graphs and analyzed them with spoken and written text (multimedia), and all the contents were relevant to the ideas of the lesson (coherence). She placed relevant text next to the graphics, helping viewers understand the ideas in the video (contiguity). She had a conversational tone ("As I move [the vertical line], uh oh, look what happens!"), using personal pronouns and avoiding overly technical phrasing (personalization), and she did not simply read the text (redundancy). She highlighted visual components (e.g., she circled the word *input*) to reinforce what had been said, and she stopped several times to explain the content to viewers (modality) on the basis of what she had just written. Note that these design principles can be met even by amateur video creators because the principles are focused on what is included and where, not on high-end animations or graphic quality.

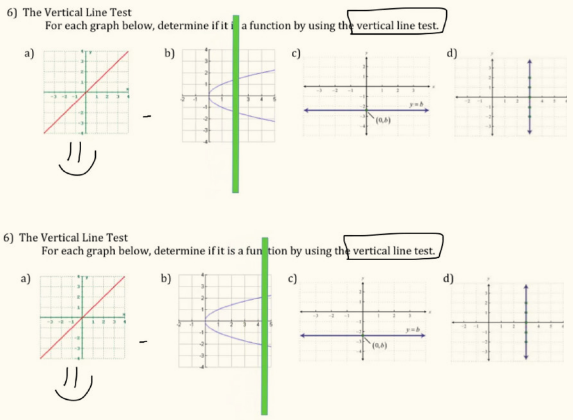
In reviewing a number of video lectures found online, we saw many video creators adhering to these principles, but we also identified some common ways video creators violated these principles. A video that exhibits the Multimedia principle might show a problem being discussed as it is displayed visually. That same video would also exhibit the Coherence principle if the remainder of the visual field is kept clear of extraneous objects or sounds. A video would exhibit the Modality and Redundancy principles if the teacher in the video explains ideas verbally and goes beyond what is shown on the screen; she does more than simply read a problem and narrate her work but also connects to prior lessons and adds justifications that support what is being shown. Both of these examples would adhere to the Personalization principle if the viewer can see that authentic human beings are speaking in a natural manner.

With regard to violations of the multimedia design principles, some videos consisted of narrations over Microsoft® PowerPoint® slides that had a preponderance of text without accompanying graphics. Furthermore, some narrators tended to read the text (and symbols) directly without much inflection or added verbal content. Videos such as these were in violation of the Multimedia, Redundancy, and Personalization principles. Other videos included a number of graphical representations of functions; however, the narrator did not always explain what the viewer was to note from these representations (violating the Modality principle), and related objects—such as equations and graphs—were sometimes not in proximity (violating the Contiguity principle). Finally, we reviewed a number of videos that included extraneous memes and pictures unrelated to the mathematical topic. In many instances, these additions seemed to be an attempt to enliven the videos, but including these irrelevant objects violated the Coherence principle.

Interactivity

Our final criteria for lecture videos is whether they engage students in more than just passive watching.

Fig. 2



The consecutive screenshots from Ms. Maynard's (2015) iBook video show that the green segment moved left and right as she talked about the function values.

Fig. 3

This image from a setup video by Meyer (2016) has a clear mathematical problem to be solved. The Desmos activity can be found at https://teacher .desmos.com/activitybuilder/custom/56e0b6af0133822106a0bed1#preview /c7ddfcac-eb96-4e2f-87c4-3b530dabbd40.

We consider two interactive elements: digital interactive features (e.g., quizzes, applets, discussion boards) and virtual manipulatives.

Maynard's video included spaces for explicit viewer participation where she asked students to pause and provided wait time for them to solve a problem before proceeding. In the iBook section, Maynard assigned specific questions to which students could digitally submit their answers. She also asked a series of reflection questions related to the lesson at the end of the video. These embedded components established two-way communication, which enabled Maynard to evaluate students' progress and informed subsequent in-class activities. However, many lecture videos available online do not create opportunities for interactivity between narrator and viewers. Although some videos include questions presumably for the students (e.g, "Why?"), they are typically answered immediately by the narrator. Students are usually not given sufficient wait time to process the question nor are they given a mechanism to explicitly respond.

Virtual manipulatives—dynamic and interactive online objects that allow for the construction of mathematical knowledge (Moyer-Packenham and Westenskow 2013)—can enhance a video's interactivity. Maynard's video did not have this particular facet of interactivity, but she did include a dynamic representation that was directly related to a mathematical idea. She showed an animated vertical line moving across graphs to test whether they were functions (see figure 2). A true virtual manipulative, however, would allow students to drag the vertical line and perform the test firsthand. In that way, students would play a more active role in the content they consume via engaging and controlling the physical actions of the virtual manipulatives. For an example of a Vertical Line test applet, visit https://www.geogebra.org/m/EsxzaeZj, created by Irina Boyadzhiev using GeoGebra.

SETUP VIDEOS

Although lecture videos abound, another type of video might be more appropriate for those wishing to flip in ways that spur collaborative learning opportunities in class—*setup videos* (de Araujo, Otten, and Birisci 2017b). These videos do not explain mathematical ideas but instead pose a problem or establish a nonmathematical context to intrigue students about what will happen the next day in class. We distinguish among setup videos according to the clarity of the mathematical idea or problem contained therein. We are not contending that more clarity is necessarily better, just that the way in which the mathematical idea arises in the setup video will have implications for how it is used in the lesson overall.

In some setup videos, the mathematical problem is clear. For example, Dan Meyer has used videos in which the mathematical question is unambiguous. In figure 3, it is fairly natural to wonder whether the ball will go through the hoop, and some necessary mathematical elements for working on the problem are visible in the video (e.g., the point of release, the path of the ball, the hoop). In these setup videos, the questions are obvious, even though the answers are not (watch videos from Meyer in supplemental files).

In other videos, no single mathematical problem stands out, but one or more could arise with guidance from the teacher. For instance, a video about the waistlines of Disney princesses could generate several different mathematical problems related to ratios. Although multiple mathematical goals are possible, a teacher might direct the class toward determining mathematically which original princess design is the most unrealistic (e.g., a very small ratio between waist width and head width) and which revised version is the most realistic (e.g., comparing waist-head ratios of the redesigned princesses to waist-head ratios of real people). Additionally, some nonmathematical questions could arise from the video (e.g., what are the implications of these body images being presented in mainstream society?). A teacher using this kind of setup video will have to navigate a multitude of questions and steer the lesson toward relevant mathematical or social goals.

A third type of setup video is where no discernible mathematical connection is in the video itself but it may establish a context for some mathematics in class. Examples of this type of video are numerous, such as having students watch a video of a music concert because the next day's in-class activity will be about concert tickets. Or an elementary school class may watch a video about a crayon factory in anticipation of a fraction comparison lesson that will involve partially filled crayon boxes. Overall, flipped instruction that uses setup videos can begin lessons with students' thoughts about the problem rather than the teacher's exposition about the concepts. It also allows students to think individually about how they might approach a problem, leading to greater diversity of solutions than if they were shown worked examples first.

With regard to selecting or creating setup videos, we recommend beginning by thinking about the mathematical goal and the in-class activity you desire. Then you can decide whether you want to use a video that clearly lays out the mathematical problem (so students can get started thinking about it), one that has the problem subtly embedded (but a diversity of questions might arise), or one that introduces the relevant context. In any case, having students watch the setup video at home may allow you to maximize the use of in-class time for collaboration and teacher-led discussions.

Table 1 Framework of Flipped Video Quality

Lecture Videos			Setup Videos
Mathematical Quality	Multimedia Design	Interactivity	Clarity of Mathematical Goal/Problem
• Richness and development of the mathematics • Precise language • No unmitigated mathematical errors	• Multimedia principle • Contiguity principle • Modality principle • Redundancy principle • Coherence principle • Personalization principle	• Digital interactive features (e.g., embedded questions) • Virtual manipulatives	◦ Mathematical goal or problem is clearly evident ◦ Mathematical goal or problem is evident with clarification or specification ◦ Mathematical goal or problem is not evident

CONCLUSION

Flipped instruction is a hot topic in mathematics education, and being thoughtful about the forms of flipped instruction is important so that it might be a true innovation rather than another educational fad. Lecture videos are common, yet not all lecture videos are of equal quality. The framework presented in this article (see table 1) provides a way to consider quality as you select or design instructional videos. The framework also reveals that teachers, when enacting flipped instruction, must think beyond mathematics and also consider design features and digital ways of making the videos interactive for students.

The framework also brings attention to the category of setup videos. Because these videos are rarer than lecture videos, the framework does not provide as much detail about them, but the mathematics education community certainly has a wide range of expertise on which to build. For example, teachers who have had success launching rich mathematical tasks in person may think about how an effective launch could incorporate video. We invite readers to consider this form of flipped instruction as a contrast to the lecture-based form.

We emphasize that this framework does not include all aspects of quality. For instance, teachers should consider an appropriate duration that maintains viewers' attention and efficiently addresses the learning goals. Another key consideration goes beyond the video itself and involves how the video relates to the associated in-class activity. The in-class time is our most precious resource because it is when we can directly influence and monitor students' opportunities to learn. Therefore, although thoughtfully evaluating videos is important, planning for the in-class time that the flip has freed up is just as (if not more) important. Overall, we can aim for high-quality videos *and* dynamic in-class activities that will achieve the innovative potential of flipped instruction.

REFERENCES

Ball, Deborah Loewenberg, Hyman Bass, and Heather C. Hill. 2011. "Measuring the Mathematical Quality of Instruction: Learning Mathematics for Teaching Project." *Journal of Mathematics Teacher Education* 14, no. 1 (February): 25–47.

Bergmann, Jonathan, and Aaron Sams. 2012. *Flip Your Classroom: Reach Every Student in Every Class Every Day*. Eugene, OR: International Society for Technology in Education.

Clark, Ruth Colvin, and Richard E. Mayer. 2007. *E-Learning and the Science of Instruction: Proven Guidelines for Consumers and Designers of Multimedia Learning*. 2nd ed. New York: John Wiley and Sons.

de Araujo, Zandra, Samuel Otten, and Salih Birisci. 2017a. "Mathematics Teachers' Motivations for, Conceptions of, and Experiences with Flipped Instruction." *Teaching and Teacher Education* 62 (February): 60–70.

———. 2017b. "Conceptualizing 'Homework' in Flipped Mathematics Classrooms." *Journal of Educational Technology & Society* 20, no. 1 (January): 248–60.

Karp, Karen S., Sarah B. Bush, and Barbara J. Dougherty. 2014. "13 Rules That Expire." *Teaching Children Mathematics* 21, no. 1 (August): 18–25.

Maynard, Tara. 2015. Chapter 4: Functions [e-Book coursepack]. Author.

Meyer, Dan. 2016. "[Updated] Will it hit the hoop?" dy/dan, March 23. Retrieved from https://blog.mrmeyer.com/2016/updated-will-it-hit-the-hoop/

Moyer-Packenham, Patricia S., and Arla Westenskow. 2013. "Effects of Virtual Manipulatives on Student Achievement and Mathematics Learning." *International Journal of Virtual and Personal Learning Environments* 4 (July): 35–50.

National Governors Association Center for Best Practices (NGA Center), and Council of Chief State School Officers (CCSSO). 2010. *Common Core State Standards for Mathematics*. Washington, DC: NGA Center and CCSSO.

Oehrtman, Michael, Marilyn Carlson, and Patrick W. Thompson. 2008. "Foundational Reasoning Abilities That Promote Coherence in Students' Function Understanding." In *Making the Connection: Research and Practice in Undergraduate Mathematics*, edited by Marilyn P. Carlson and Chris Rasmussen, pp. 27–42. Washington, DC: Mathematical Association of America.

Smith, D. Frank. 2014. "How Flipped Classrooms Are Growing and Changing." *EdTech Magazine*, June 12.

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