MASTER THESIS

Design Guidelines for Instructional Videos in Secondary Mathematics Education: Exploring Student and Teacher Preferences

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Abstract

Recent technological and educational developments led to an increased need for well-designed *instructional videos*, which are videos intended to help people learn targeted material. Instructional videos offer many advantages for student learning and engagement, especially for complex subjects like mathematics. Over the past years much progress has already been made to understand when instructional videos do or do not produce these learning benefits, particularly in higher education. The current study adds to this research base by exploring to what extent research-based design guidelines for multimedia learning match the preferences of students and teachers in Dutch secondary mathematics education. The results of a survey (N=175), students focus groups (N=21) and teacher interviews (N=2) revealed that many of the general design guidelines for multimedia learning also apply to instructional videos for secondary mathematics education. This study, however, did pinpoint a few design aspects that seem to differ for this specific subject: the complexity of mathematical problems asks for on-screen text, such as mathematical formulas and equations, and the pace of the videos should enable students to write along the worked-examples often used in this type of videos. In addition, the results suggest that some design features are not yet commonly used in instructional videos for this subject, such as segmentation into meaningful chapters and activating (interpolated) questions. The current study identified many valuable directions for further research, whilst providing educational professionals with new insights in how to design and select future instructional videos for mathematics to best serve students' learning and engagement in secondary education.

Key words: instructional videos, mathematics, secondary education, design guidelines.

1. Introduction

The use of instructional videos in formal education has increased massively in the past decade (De Koning, Hoogerheide, & Boucheix, 2018; Fiorella & Mayer, 2018). Nowadays, video is even considered as one of the most popular ways of delivering instruction (De Koning et al., 2018). The rise of instructional videos has been stimulated by several developments on both the supply and the demand side. First, the production of instructional videos has become more accessible by an increasing number of easy-to-use software programs for video editing (Van der Meij & Van der Meij, 2013). On the demand side, the rise of online learning environments stimulated the need for digital instructional resources, including instructional videos (Clark & Mayer, 2016; Zhang, Zhou, Briggs & Nunamaker, 2006). Moreover, the outbreak of COVID-19 forced schools and universities all over the world to switch to remote learning. This recent change boosted the need for well-designed instructional videos even more.

The use of instructional videos offer various advantages for both students and teachers. Well-designed instructional videos have a positive impact on student attitudes, behaviour, and learning performance (Kay, 2012; Kay & Kletskin, 2012). They allow students to learn at their own pace, place and time (Kay, 2012). Moreover, teachers can enhance students' motivation and learning by incorporating instructional videos in their teaching practice, for example as preparation for a test or as part of classroom lectures (Brecht & Ogilby, 2008; Kay 2012).

Over the past years, much progress has already been made to better understand when instructional videos do or do not produce learning benefits (De Koning et al., 2018; Fiorella & Mayer, 2018). Theoretical frameworks including the Cognitive Theory of Multimedia Learning (Mayer, 2014a) show that students need to actively engage in the viewing process in order to learn from instructional videos. However, instructional videos vary considerably in how well they are appreciated and how often they are viewed (Ten Hove & Van der Meij, 2015). The proliferation of available videos also makes it hard for students and teachers to find the ones that enhance student engagement and learning (Shoufan, 2017). Correspondingly, educational publishers are in need of clear design guidelines for the production of future instructional videos (R. Houtenbos, personal communication, April 14, 2020).

Although prior research on *multimedia learning*, that is learning from a combination of words and pictures (Mayer, 2014b), has produced various research-based principles for the effective design of instructional videos (e.g. De Koning et al., 2018; Fiorella & Mayer, 2018), it is not clear whether these guidelines also fit the needs of students in secondary education. Empirical research into effective design features of instructional videos was generally conducted in higher education (Kay, 2012). Moreover, design guidelines for instructional videos may differ depending on the complexity of the subject or the type of knowledge being taught (Paas & Sweller, 2014; Van der Meij, 2013). The current study focused on the subject of mathematics, a complex subject where instructional videos provide great opportunities to teach students how to solve abstract mathematical problems (Kay & Kletskin, 2012). The aim of this study was to explore to what extent general research-based design guidelines for multimedia learning match the preferences of students and teachers in secondary mathematics education.

2. Theoretical Framework

There is a considerable body of research on *multimedia learning* (i.e., learning from a combination of words and pictures; Mayer, 2014b) that provides important insights into how instructional videos should be designed to promote student learning and engagement (e.g., Brame, 2016; Clark & Mayer, 2016; Fiorella & Mayer, 2018; Mayer, 2014d). This chapter starts with a definition of instructional videos and their potential benefits, and subsequently describes general design guidelines for instructional videos that can be obtained from cognitive theories and recent empirical research.

2.1 Instructional Videos

Videos can be used in education for various purposes, for example to trigger discussion or to show real-world demonstration (Winslett, 2014). The focus of this study is on *instructional videos*, which are intended to help people learn targeted material (Fiorella & Mayer, 2018), also known as video lectures (e.g. Brecht & Ogilby, 2008; Chen & Wu, 2015) or video podcasts (e.g. Kay, 2012; Kay & Kletskin, 2012). Instructional videos are a form of multimedia instruction when they include both visual and verbal material (Fiorella & Mayer, 2018).

Many studies show that instructional videos can positively impact student attitudes, behaviour and learning performance (Kay, 2012). A literature review by Kay (2012), analysing 53 peer-reviewed studies on instructional videos from 2002 to 2011, revealed various benefits for the use of instructional videos. First, students see instructional videos as useful, helpful and effective with respect to improving the learning process, as well as enjoyable, satisfying, motivating, and intellectually stimulating. Moreover, the review showed that students use instructional videos to improve learning, to increase control over learning and to make up for missed classes. Students particularly like that instructional videos permit them to learn when, where and at the pace they want (Kay, 2012). Furthermore, multiple studies in the review show that instructional videos positively impact student behaviour. Students often watch instructional videos and spent considerable time watching them, especially prior to a test or examination (Kay, 2012). Other reasons for watching instructional videos that were revealed in the literature review include preparing for class, self-checking for understanding, obtaining a global overview of chapters read, and taking better notes. The use of instructional videos can even lead to more independence, increasing self-reflection, more efficient test preparation, and reviewing material more frequently (Kay, 2012). Finally, some studies in the review show that instructional videos can have a direct and positive impact on test and skill performance.

However, not all instructional videos do produce these learning benefits (Kay, 2012). Although research on the impact of instructional videos on learning is more positive than neutral, some studies in the literature review of Kay (2012) reported that instructional videos had no significant impact on learning performance (e.g., Bennet & Glover, 2008; Hill & Nelson, 2011). None of these studies examined why instructional videos had no impact on learning (Kay, 2012). Another major challenge in the use of instructional videos is that many students prefer face-to-face lectures over instructional videos (Kay, 2012). Given explanations include that current instructional videos are not sufficient to support students' needs (Chester, Buntine, Hammond & Atkinson, 2011) and are less engaging than lectures (Foertsch, Moses, Strikwerda & Litzkow, 2002). To overcome these challenges, instructional videos should be designed in the light of how people learn (Mayer, 2014a).

2.2 Cognitive Theories

The Cognitive Theory of Multimedia Learning by Mayer (2014a) addresses how people learn from multimedia instructional messages, such as instructional videos. Mayer's theory is based on the idea that people have separate channels for processing verbal and visual material (*dual-channels assumption*), that each channel can process only a small amount of material at a time (*limited capacity assumption*), and that meaningful learning involves engaging in appropriate cognitive processing during learning (*active processing assumption*). The challenge for the design of instructional videos is to guide the learner's appropriate cognitive processing during the learning process without overloading the learner's working memory capacity (Mayer, 2014a).

Cognitive overload takes place when the learner's intended cognitive processing exceeds the learner's available cognitive capacity (Mayer & Moreno, 2003). The Cognitive Load Theory (Paas & Sweller, 2014) distinguishes between three types of cognitive load that are considered to be additive. First, *extraneous load* requires learners to use working memory resources to process elements that do not lead to knowledge acquisition. Second, *intrinsic cognitive load* is the cognitive load due to the natural complexity of the information that must be processed. Lastly, *germane cognitive load* refers to the working memory resources devoted to dealing with intrinsic rather than extraneous interacting elements, thus facilitating learning (Paas & Sweller, 2014).

Consistent with the Cognitive Load Theory, the Cognitive Theory of Multimedia Learning specifies three kinds of demands on the learner's information processing system during learning: extraneous processing, essential processing, and generative processing (Mayer, 2014a). Mayer (2014a) describes e*xtraneous processing* as the processing of extraneous elements that do not support the instructional goal. He states that this cognitive demand can be addressed by devising instructional methods aimed at *reducing extraneous elements*. Next, e*ssential processing* is aimed at mentally representing the presented material in working memory and is caused by the complexity of the material, according to Mayer (2014a). Mayer argues that this cognitive demand can only be altered by changing the nature of the task or the knowledge levels of the learners. Consequently, the design of instructional videos should seek to *manage essential processing* (Mayer, 2014a). Finally, Mayer describes g*enerative processing* as the cognitive processing aimed at making sense of the presented material. According to Mayer, this demand on the working memory results in the construction of an integrated mental model and is caused by the learner's motivation to learn. Therefore, the design of instructional videos should *foster generative processing* (Mayer, 2014a).

In sum, the design of instructional videos should guide the learner's appropriate cognitive processing by minimizing extraneous processing, by managing essential processing and by fostering generative processing (Mayer, 2014a). The next paragraphs provide a review of empirical research regarding techniques that can be used in the design of instructional videos to guide these types of processing.

2.3 Design Guidelines for Minimizing Extraneous Processing

Poorly designed instructional videos can force learners to expend large amounts of processing capacity on the processing of irrelevant material, leaving them with too little capacity for the selection, organisation and integration of essential material (Mayer, 2014a). As summarized in Table 1, instructional techniques aimed at reducing this extraneous processing include coherence principle, signalling principle, redundancy principle, spatial contiguity principle, and temporal contiguity principle.

Coherence

Multiple studies have shown that instructional videos should only include images, sounds and text that are relevant to the content of the lesson in order to enhance learning (e.g., Moreno & Mayer, 2000; Mayer, Heiser & Lonn, 2001; Ibrahim, Antonenko, Greenwood & Wheeler, 2011). Mayer and Fiorella (2014) refer to this instructional technique as the *coherence principle*. Irrelevant material, such as background music or environmental sounds

(Clark & Mayer, 2016; Moreno & Mayer, 2000; Boeckmann, Nessmann, Petermandl & Stückler, 1990; Furnham & Strbac, 2002) and complex backgrounds (Merkt, Lux, Hoogerheide, Van Gog & Schwan, 2020), require the learner to judge whether he or she should be paying attention to them, which increases extraneous load and can reduce learning (Brame, 2016). By *weeding* these extraneous materials, the retention and transfer from new information from instructional videos can be improved (Ibrahim et al., 2011).

Table 1

Research-based Design Guidelines for Managing Cognitive Load

Instructional technique	Design guideline for instructional videos
Coherence principle	Only include details that are relevant to the content of the lesson. Eliminate extraneous materials.
Signalling principle	Use a combination of visual and verbal cues to guide students' attention to relevant material.
Redundancy principle	Avoid redundant on-screen text.
Spatial contiguity principle	Place on-screen text near corresponding graphics.
Temporal contiguity principle	Present corresponding narration and graphics at the same time.

Signalling

Another technique that helps to minimize extraneous processing is *signalling*, which is the use of cues in multimedia learning materials that guide learners' attention to the relevant elements of the material or highlight the organization of the material (Van Gog, 2014). These cues can be either visual (e.g., arrows and colour coding) or auditory (e.g., the instructor's intonation and the use of significant pauses for emphasis), and can be incorporated into text, pictures, or both (Van Gog, 2014; Xie, Mayer, Wang & Zhou, 2018). Studies have shown that signalling improves students' ability to retain and transfer new knowledge (De Koning et al., 2009; Ibrahim et al., 2011; Mayer & Moreno, 2003).

A recent study of Xie et al. (2018) shows that signalling improves student performance even more when *coordinated dual-modality cueing*, that is visual and auditory cueing synchronized in time, is used. They found that students spent more time attending to the relevant portion of the graphic and performed better on post-tests when a key element was spoken with deeper intonation (auditory cue) whilst the corresponding element in the graphic turned red at the same time (visual cue). Moreover, coordinated visual and verbal cues also resulted in better performance than presenting only visual or auditory cues, or presenting the two cues in unmatched or unsynchronized ways (Xie et al., 2018).

Redundancy

Extraneous processing can also be reduced by *eliminating redundant on-screen text*, that is written text which is a duplicate of the narration (Clark & Mayer, 2016; Mayer & Fiorella, 2014). Clark and Mayer (2016) argue that on-screen text shifts students' attention away from the essential material presented in the graphics. Moreover, learners may try to compare and reconcile the written text with the narration, which requires cognitive processing that is not needed for learning the content (Clark & Mayer, 2016). By eliminating redundant on-screen text, the problem of having to process both graphics and printed words in the visual channel is removed (Mayer & Fiorella, 2014).

In some cases, however, the use of on-screen text should be considered in the design of instructional videos. For example, a few key words of the narration can be used to direct learner's attention when presented next to the corresponding graphic (Mayer & Johnson, 2008). Moreover, subtitles might help learners that are likely to have difficulty with processing spoken words, for example when a video contains speech in the learner's second language (Clark & Mayer, 2016; Mayer, Fiorella & Stull, 2020).

Spatial Contiguity

When words and pictures are separated from one another on the screen, learners need to visually scan the screen to integrate the information they hold (Ayres & Sweller, 2014). This leads to extraneous load, since learners are required to split their attention between and mentally integrate several sources of physically disparate but essential information. By *placing the material near each other*, learners can store them together in their working memory and therefore make meaningful connections between them (Clark & Mayer, 2016). This is also known as the *spatial contiguity principle* (Ayres & Sweller, 2014).

Temporal Contiguity

A similar way to reduce extraneous processing is by *presenting corresponding narration and graphics at the same time* (Clark & Mayer, 2016; Mayer & Fiorella, 2014). When corresponding narration and graphics are separated in time, extraneous processing is caused by maintaining a mental representation in working memory for a long period of time (Mayer & Fiorella, 2014). By presenting corresponding narration and graphics in instructional videos at the same time, the learner can more easily make mental connections between the material (Clark & Mayer, 2016). This instructional technique is in line with *the temporal contiguity principle*, which holds that students learn better when corresponding words and pictures are presented simultaneously rather than successively (Ayres & Sweller, 2014).

2.4 Design Guidelines for Managing Essential Processing

Although intrinsic cognitive load is caused by the natural complexity of the task, there are some ways through which the design of instructional videos can help to make the essential processing concerned with this type of cognitive load more manageable. Instructional techniques that help control the processing of essential material include the segmenting principle, the pre-training principle and the modality principle, as summarized in Table 2.

Table 2

Theoretical Design Guidelines for Managing Essential Processing

Instructional technique	Design guideline for instructional videos
Segmenting principle	Divide videos into meaningful segments.
	Include learner-controlled or system-paced pauses.
Pre-training principle	Include a preview of the key concepts or procedures at the start of the video.
	Activate prior knowledge with a review of relevant concepts or procedures.
Modality principle	Use spoken rather than written text.

Segmenting

The first technique that can be used in the design of instructional videos to manage essential processing is *segmenting*, which refers to the chunking of information within the video into meaningful segments (Brame, 2016; Mayer & Pilegard, 2014). This technique provides learners with additional time to perform cognitive processes necessary for learning, whilst emphasizing the structure of the video content (Spanjers, Van Gog, Wouters & Van Merriënboer, 2012). Many studies have shown the importance of segmenting for both learning from instructional videos (Ibrahim et al., 2011; Mayer & Moreno, 2003; Zhang et al., 2006) and student engagement with instructional videos (Guo, Kim & Rubin, 2014; Zhang et al., 2006). These findings are consistent with the *segmenting principle*, that states that people learn more deeply when a multimedia message is presented in learner-paced segments rather than as a continuous unit (Mayer & Pilegard, 2014).

Including *learner-controlled pauses* gives learners the possibility to decide when they want to start the next segment, whilst also involving learners more actively in the learning process (Wouters, Tabbers & Paas, 2007). Many studies (e.g., Hasler, Kersten, & Sweller, 2007; Mayer & Chandler, 2001; Moreno, 2007) showed that this type of segmentation leads to a decrease in perceived cognitive load and better performance on transfer tests. More recent studies of Spanjers, Wouters, Van Gog and Van Merriënboer (2011) and Spanjers et al. (2012) showed that instructional videos with incorporated *system-paced pauses*, after which the video continues automatically after two seconds, also lead to higher student performance compared to non-segmented videos.

Pre-training

Another solution to manage essential processing is to equip learners with knowledge that will make it easier to process the information in the video (Mayer & Pilegard, 2014). One way to achieve this is by providing learners with a *preview of the key concepts* or procedures at the start of the instruction. A preview of the content that is being taught in the video illustrates the instructional goal and helps learners orient on the structure of the information (Van der Meij & Van der Meij, 2013). This technique is in line with the *pretraining principle*, which holds that the names and characteristics of key elements in a video should be described before the start of the actual instruction (Mayer & Pilegard, 2014).

Learners can also be helped to process the information in a video by starting instructional videos with a *review of the prior knowledge* that is needed to process the pictorial and verbal information in the video. In order to learn, learners have to integrate this new information with relevant knowledge that is already stored in their long-term memory (Mayer, 2014a). By activating this prior knowledge related to concepts being taught, students can build on or challenge their current understanding (Kay, 2014).

Modality

The final instructional technique that helps to manage essential processing stems from the dual-channel assumption of the Cognitive Theory of Multimedia Learning. One consequence of this assumption is that instructional videos should combine visual and verbal material to make the information that need to be processed more manageable (Low & Sweller, 2014; Mayer & Pilegard, 2014). Text in instructional videos can be either spoken or written. Several studies have shown that spoken text alongside visuals leads to better learning performance than visuals combined with written text (see Low & Sweller, 2014 for an overview). By presenting a part of the essential information in visual mode and the rest of the essential information in auditory mode, the effective working memory capacity can be expanded, also known as the *modality effect* or *modality principle* (Low & Sweller, 2014; Mayer & Pilegard, 2014).

2.5 Design Guidelines for Fostering Generative Processing

When the design of instructional videos succeeds in managing intrinsic cognitive load and limiting extraneous load, sufficient mental resources can be expended to process and comprehend the material (Mayer, 2014a). Since this generative processing is caused by the

learner's motivation to commit to active cognitive processing, the design of instructional videos should promote student engagement. Moreover, generative processing can be promoted by directing learners towards sense-making activities. Instructional techniques that foster generative processing include the multimedia principle, the voice principle, the image principle and the personalisation principle (see
). Other techniques stem from recent empirical research into student engagement in instructional videos and cover the instructional medium used, the video-length and ways to stimulate active learning.

Table 3

Research-based Design Guidelines to Foster Generative Processing

Instructional technique	Design guideline for instructional videos
Visuals - Multimedia principle	Combine text with (functional) graphics. • Use animations to illustrate hands-on procedures or to serve an interpretive function. • Use static pictures to illustrate conceptual knowledge.
Narration - Personalization principle - Voice principle	Use an informal, conversational style. Use a human voice speaking with a standard accent. Use enthusiastic, fast-speaking instructors. Edit out pauses and filler words in post-production.
Human embodiment - Image principle - Embodiment principle	A visible instructor might enhance learning by conveying a sense of social presence and guiding students' attention. Use adult models rather than peer models when the skilled to be learned is viewed as more appropriate for adults.
Instructional medium	Use handwriting and -drawing to engage students. A mixed approach of handwriting and typed text might be useful to engage students whilst offering a clear, legible presentation.
Video length	Keep instructional videos short (max. 6 minutes). Segment longer videos into chunks of max. 6 minutes.
Active learning	Include interpolated questions. Use interactive features that give students control. Make video part of a larger homework assignment . Provide students with a predefined summary.

Visuals

The first technique that can be used in the design of instructional videos to foster generative processing is the use of functional visuals to accompany spoken or written text. According to the *multimedia principle*, learning from a combination of text and visuals is more effective than learning from text or visuals alone (Mayer, 2014b). Clark and Mayer (2016) argue that multimedia presentations can encourage learners to engage in active learning by mentally representing the material in words and in pictures, and by mentally making connections between the pictorial and verbal representations.

Whilst it is important to add visuals to words, not all graphics are equally useful (Clark & Mayer, 2016). To enhance learning, visuals should be directly related to the instructional goal: decorative and seductive visuals should be minimized, whereas visuals that help learners understand or organize the material should be used (Clark & Mayer, 2016). Besides the function of the visuals, the type of visuals can also effect learning from instructional videos. Visuals can be either static, such as drawings, charts, graphs, maps or photos, or dynamic, such as animation or video (Clark & Mayer, 2016). Although animated visuals can depict changes and movement, they are not always more effective than a series of static frames depicting the same material. One explanation is that the more passive medium of illustrations and text actually allows for active processing, because the learners have to mentally animate the changes from one frame to the next, and learners are able to control the order and pace of their processing. Moreover, animation may impose extraneous cognitive load because the images are so rich in detail and transitory that they must be held in memory (Clark & Mayer, 2016). It appears that static visuals might be more effective to promote understanding of conceptual information, whereas animated visuals may be more effective to teach hands-on procedures (Clark & Mayer, 2016). The effectiveness of animations can be improved through the use of visual cueing in order to direct attention or to show relation and organization (Clark & Mayer, 2016; see also the paragraph about signalling).

Narration

Another method to keep students engaged is by using an informal, conversational narration style, also known as the *personalization principle* by Mayer (2014). The use of a conversational style rather than formal language during multimedia instruction has been shown to have a large effect on students' learning (Ginns, Martin & Marsh, 2013; Mayer, 2014c). An explanation for this could be that a conversational style encourages students to develop a sense of social partnership with the narrator, which leads to greater engagement and effort (Mayer, 2008). A conversational style can be characterized by the use of first or second person instead of third person, the use of sentences that directly address the learner, by using forms of address that are more polite and by making the instructors views and personality more visible (Ginns et al., 2013).

The instructor's narrative voice also affects students' engagement with instructional videos. In line with the *voice principle*, several researchers argue that a human voice is preferable over a computer voice because of greater naturalness and attractiveness (e.g., Baylor, 2011; Mayer, 2014c; Van der Meij & Van der Meij, 2013). Moreover, a human voice with a foreign accent might also affect learner's social response and cognitive processing of the message (Mayer, 2014c). Therefore, a human voice with a standard accent is recommended in the design of instructional videos.

Additionally, generative processing is affected through student engagement by the instructor's narrative speed. Studies show that students engage more with videos with faster speaking instructors (Guo et al., 2014; Ten Hove & Van der Meij, 2015). For example, Guo et al. (2014) found that when presenters spoke with a rate of 185 words per minute or more, viewer engagement was found to increase significantly. Results from this study also revealed that fast-speaking instructors conveyed more energy and enthusiasm, which might have contributed to the higher engagement for those videos. They recommend not to force instructors to speak faster, but rather to bring out their enthusiasm and reassure them that there is no need to artificially slow down. Moreover, in post-production pauses and filler words could be edited out to make the speech more fluent (Guo et al., 2014).

Human Embodiment

Another aspect of instructional videos that can be used to promote generative processing is human embodiment, that is the presence of a visible instructor (Chorianopoulos, 2018). Over the last years, research into human embodiment in instructional videos has produced mixed results. In line with the *image principle*, that states that people do not necessarily learn more deeply from a multimedia lesson when the speaker's image is added to the screen, several studies found no direct effect of instructor presence on learning (e.g., Homer, Plass, & Blake, 2008; Kizilcec, Papadopoulos & Sritanyaratana, 2014; Van Wermeskerken, Ravensbergen & Van Gogh, 2018). Moreover, some studies showed that the instructor's image might even distract learners from the relevant learning content (Van Wermeskerken et al., 2018; Wang & Antonenko, 2017).

However, the use of a visible instructor does seem to benefit student learning in more indirect ways. For example, Guo et al. (2014) found that students engaged more with talking-head videos (i.e. videos in which the instructor is talking directly into the camera). Possible explanations the researchers gave are that a human face provides a more "intimate and personal" feel and breaks up the monotony of PowerPoint slides and code screencasts. Moreover, in the study of Wang and Antonenko (2017) instructor presence produced a significant positive effect on participants’ perceived learning, satisfaction, and mental effort, which contribute to learner motivation and engagement in autonomous and self-regulated online learning environments (Wang & Antonenko, 2017). Furthermore, studies of Ouwehand, Van Gog and Paas (2015) and Van Wermeskerken et al. (2018) suggest that the fact that the instructor attracts learners’ attention, can be used to guide learners’ attention when the instructor employs social cues such as gaze and/or gesture cues, or when the instructor manipulates objects. These findings are in line with the *embodiment principle*, that people learn better when on-screen agents display humanlike gesturing, movement, eye contact, and facial expressions.

Recent studies have also explored how different characteristics of a visible instructor, such as gender and age, affect students’ learning and engagement. According to the model-observer similarity hypothesis (Schunk, 1987), these instructor characteristics may affect learning when learners can identify themselves with the instructor. However, recent studies did not find these effects for gender (Hoogerheide, Loyens, & Van Gog, 2018) nor age (Hoogerheide, Van Wermeskerken, Loyens, & Van Gog, 2016). In contrast, Hoogerheide et al. (2016) found that learners who studied adult models invested less effort and attained better learning outcomes than those who studied peer models. Students also rated the adult models’ explanations as being of higher quality, even though the content of the examples was exactly the same. Moreover, the videos including an adult instructor were perceived to provide a better explanation and resulted in better learning outcomes than videos with a peer instructor. Hoogerheide et al. (2016) recommend designing and using video modelling examples with an adult model rather than a peer model when the skill to be learned is viewed as more appropriate for adults because they are perceived more as an expert.

Instructional Medium

Similar to human embodiment, other aspects of the video production style may promote generative processing. One example is the instructional medium used to present the information in an instructional video. The type of instructional media can range from physical (e.g., instruments, board) to digital (e.g., slides, digital drawing board, animation and simulation; Chorianopolous, 2018). Over the last years, studies have demonstrated mixed effects of different instructional media on students’ learning and engagement. Some research suggest that physical media should be used to improve students’ learning and engagement (e.g., Fiorella & Mayer, 2016; Guo et al., 2014). For example, Fiorella and Mayer (2016) found that students with lower prior knowledge performed significantly better on the transfer test when they received a video lecture with the instructor or the instructor’s hand drawing graphics while lecturing rather than pointing at already drawn graphics. Mayer et al. (2020) refer to this as the dyn*amic drawing principle*. Likewise, Guo et al. (2014) found Khan-style (i.e., the recording of a pen-tip on a digital drawing board) to be more engaging than slides or coding sessions.

In contrast, Cross, Bayyapunedi, Cutrell, Agarwal and Thies, (2013) found mixed results when they compared handwritten tutorials versus typed presentations for online educational videos. They found that some learners did prefer handwriting because it is more personal, more natural and more engaging, but other learners preferred typed presentations as they were clearer and better legible. Cross et al. (2013) explored the use of TypeRighting, a new approach that fades digital handwriting into typed text soon after it appears and found that students preferred TypeRighting over handwritten and typed text.

Video-length

Furthermore, the length of instructional videos have also shown to impact generative processing. The importance of video length for engaging students, was demonstrated in various studies (e.g., Guo et al., 2014; Ten Hove & Van der Meij, 2015). Ten Hove and Van der Meij (2015) showed that video length and watch time significantly correlated, indicating that viewers watch a smaller percentage of longer videos. Likewise, Guo et al. (2014) and Kim et al. (2014) found that student engagement dropped significantly when the video length was longer than six minutes. Guo et al. (2014) suggest that *shorter videos* might contain higher quality instructional content, since they have to be better planned than longer videos. Additionally, Kim et al. (2014) argue that with longer videos, students might feel bored due to a short attention span or experience more interruptions. They recommend that videos should be segmented into short chunks, ideally less than six minutes.

Active Learning

Finally, recent studies have explored ways that promote generative processing by activating students to engage in sense-making activities. For example, students can be activated by providing them with guiding questions before the start of the video that they should answer while watching it (Brame, 2016; Lawson, Bodle, Houlette, & Haubner, 2006; Lawson, Bodle, & McDonough, 2007). Lawson et al. (2006; 2007) found that having students write their answers to guiding questions while watching instructional videos substantially improved their performance. Guiding questions help focus students' attention on key concepts in the video, thereby increasing the germane load of the learning task and reducing the extraneous load (Brame, 2016). This guidance may be especially important for beginning students because research on expertise suggests that novices may have difficulty identifying which information is most and least important (Lawson et al. 2006). Moreover, asking students to write answers to guiding questions encourages them to take a more active approach to learning and might also make them feel more accountable for learning the information (Lawson et al., 2007).

Another way to activate students is by using interactive elements, such as interpolated questions (i.e., questions embedded in the video; Brame, 2016; Kovacs, 2016; Szpunar, Jing, & Schacter, 2014, Szpunar, Khan, & Schacter, 2013) or navigation options (Brame, 2016; Zhang et al., 2006). Szpunar et al. (2013) demonstrated that interpolating an online lecture with testing can help students to quickly and efficiently extract lecture content by reducing the occurrence of mind wandering, increasing the frequency of note taking, and facilitating learning. Moreover, students who received the interpolated questions also reported the learning event as less “mentally taxing,” and reported less anxiety about the final test (Szpunar et al., 2013). Additionally, Kovacs (2016) examined the ways in which users engage with in-video quizzes and how they affect their viewing behaviour. He found that users engage heavily with in-video quizzes: quizzes led to peeks in seeking and rewatching activity, and in-video dropout was lower. Moreover, in-video quizzes segment the video into isolated subsections.

Zhang et al. (2006) found additional evidence for the positive effects of interactive video on students’ learning and engagement. They found that providing learners with interactive navigation options, that allow random content access, led to better learning performances and a higher level of learner satisfaction compared to settings with non-interactive video or without video (Zhang et al., 2006). The use of interactive elements in instructional videos not only has the benefit of giving students control, but can also demonstrate the organization, and thereby increasing the germane load of the content (Brame, 2016).

Videos can also promote active learning when they are part of a larger homework assignment (Brame, 2016). MacHardy and Pardos (2015) observed that videos that offered the greatest benefits to students were highly relevant to associated exercises. Moreover, Zubair and Laibinis (2015; in Brame, 2016) found that students valued video’s embedded in a larger homework assignment, whilst the videos also improved students’ understanding of difficult concepts.

Although learners must engage actively to learn from instructional videos, some forms of active engagement impede learning (Clark & Mayer, 2016). In the context of learning from text, studies of Stull and Mayer (2007) and Leopold, Sumfleth, and Leutner (2013) showed that students who were provided with a predefined summary learned more compared to students who had to generate summaries themselves. Studies of Van der Meij and Van der Meij (2016) and Van der Meij (2017) confirmed that the use of summaries leads also in the context of instructional videos to better performance and increased motivation. They argue that summaries in videos can enhance retention by structuring the information in a clear procedural way (Van der Meij & Van der Meij, 2016).

3. Present Study

The design guidelines for multimedia learning described in the previous section provide a general framework for the design of instructional videos based on cognitive theories and empirical research. The present study adds to this research base by exploring to what extent these design guidelines for instructional videos match the preferences of students and teachers in secondary mathematics education.

Based on the cognitive theories and earlier research on multimedia learning described in the theoretical framework it was hypothesized that the participants would mostly agree with the design guidelines for instructional videos in the context of secondary mathematics education. However, possible exceptions were anticipated because of three reasons: 1) research into design guidelines for instructional videos in secondary education is scarce, 2) complex subjects, such as mathematics, might ask for different design guidelines compared to less complex subjects, and 3) the preferences of the end users (i.e., students and teachers) of instructional videos might differ from recommendations based on measures of test performance. These reasons are further explained in the following paragraphs.

3.1 Instructional Videos in Secondary Mathematics Education

The current study focuses on instructional videos in secondary mathematics education. Despite the substantial amount of research that has already been conducted on design guidelines for instructional videos, the generalizability of these earlier studies to the context of secondary education is questionable. Whereas empirical research into effective design features for instructional videos was generally conducted in higher education (Kay, 2012), the needs, interests and learning preferences of a new generation of students tend to differ from earlier generations due to technological advances and social-economical changes (Seemiller & Grace, 2017).

Additionally, the focus on mathematics education is expected to be a relevant factor in the design of instructional videos. Past research has shown mathematics to be a complex knowledge domain, where students need to concurrently manage both conceptual and procedural knowledge in problem-solving (Kadir, Ngu, & Yeung, 2015). This high element interactivity (i.e., the extent to which elements of information that must be processed interact; Paas & Sweller, 2014) imposes a heavy intrinsic cognitive load on the working memory. Consequently, less cognitive capacity is available for extraneous and generative processing. This makes the design of instructional videos for mathematics education even more critical compared to less complex subjects (Paas & Sweller, 2014).

Instructional videos offer great possibilities to manage the cognitive load of mathematics as well as to fit the learning preferences of students in secondary education, especially when worked examples are included. Worked examples consist of a problem formulation and the final solution, often accompanied by the solution steps leading to this solution (Renkl, 2014). They allow students to devote all the available cognitive capacity to studying the worked-out solution procedure (i.e., the relationship between problem states and operators) and constructing a cognitive schema for solving such problems (Van Gog, Kester & Paas, 2011). Moreover, the use of worked examples in instructional videos fits the current generation's interest in learning through observation (Seemiller & Grace, 2017).

3.2 Student and Teacher Preferences

The present study is also different from earlier research by focusing on student and teacher preferences. This perspective is important to examine because these actors are the end users of instructional videos: students have to watch instructional videos in order to learn from them (Brame, 2016). Since they are often referred to instructional resources by their teachers, instructional videos should also be valued by teachers. Exploring the perceptions of both actors about effective design guidelines for students' learning and engagement could provide valuable new insights, since research on the effectiveness of design guidelines for multimedia learning is generally conducted with measures of test performance.

The focus on student and teacher preferences is also valuable for educational professionals. The outcomes of this study provide educational publishers and teachers with new insights in how to design and select future instructional videos for secondary mathematics education to best serve student learning and engagement. The need for research-based guidelines for the design of instructional videos was recognized by educational publisher Noordhoff, that offers the two most used teaching methods for mathematics in Dutch secondary education. Instructional videos were already included in the current digital editions of both teaching methods, but it was unknown whether these videos matched the needs and preferences of their end users. They commissioned this research in order to improve student engagement and learning from future videos.

4. Research Method

4.1 Research Design

A mixed methods sequential design, that is a consecutive combination of quantitative and qualitative design phases (Ivankova, Creswell & Stick, 2006), was used to identify the preferences of students and teachers in secondary mathematics education. The first, quantitative part of the study was a descriptive survey. Cohen, Manion and Morrison (2011) state that surveys are useful for gathering factual information, data on attitudes and preferences, beliefs and predictions, opinions, behaviour and experiences. Teacher and student questionnaires were used to identify their preferences for specific characteristics of instructional mathematics videos. Since the degree of explanatory potential or fine detail of a survey is limited (Ivankova, Creswell & Stick, 2006), the survey was followed by focus groups and teacher interviews to gain a more in-depth understanding of the participants' perceptions. The findings from the questionnaires and focus groups were combined with the findings of the literature review to answer the research question.

4.2 Participants

Quantitative Sample

In total, 206 students and 37 mathematics teachers from Dutch secondary schools participated in the quantitative part of the study. The teachers were selected using random sampling from the customer base of educational publisher Noordhoff, who commissioned this research. Additionally, teachers from the researcher's professional network were reached to find more participants. Teachers were asked to direct their students to the student questionnaire, hence they were included in the survey through snowball sampling.

Participants were informed at the start of the survey about all aspects of the research and had to actively consent with the use of their data to participate. Respondents who did not provide consent (N = 22) were subsequently directed to the end of the survey, and were excluded from the study. Moreover, participants who did not finish the survey (N = 32) or used straightlining (N = 14), that was defined as respondents giving identical answers for all items in a battery of questions using the same response scale (Kim, Dykema, Stevenson, Black & Moberg, 2018), were also excluded to improve data quality. This left a total of 175 participants (144 students and 31 teachers) for inclusion in the present study. Their demographic variables are reported in Table 4.

Qualitative Sample

Convenience sampling from the researcher's personal and professional network was used to create focus groups for the qualitative part of the study. The student focus groups took place at two schools for secondary education in the Netherlands. All students from the first school followed education that prepared them for university (VWO), whereas the students from the second school followed education that prepared them for vocational training (VMBO). Students were grouped based on their current grade into primary years (VMBO grade 1-2, VWO grade 1-3) or upper years (VMBO grade 3-4, VWO grades 4-6). This process led to two groups of seven students for the first school. Likewise, two groups of five students were formed from the consent forms of the second school, however only seven of these students showed up for the focus groups.

Additionally, convenience sampling from the researcher's personal and professional network was used to reach participants for the teacher focus groups. Despite several attempts to find more teachers willingly to participate, not enough teachers responded to form focus groups. Instead, two teachers from the researcher's personal network were interviewed, a female who teaches VMBO and a male who currently teaches HAVO (i.e., senior general secondary education) and VWO but also has experience with VMBO.

Table 4

Demographic Variables Survey Participants

Variable	Students (N_s = 144)		Teachers (N_t = 31)	
	N_s	%	N_t	%
Gender				
Male	56	38.9	13	41.9
Female	87	60.4	17	54.8
Unknown	1	.7	1	3.2
Grade*				
1	32	22.9	18	58.1
2	41	28.5	22	71.0
3	11	7.6	22	71.0
4	34	23.6	18	58.1
5	12	8.3	12	38.7
6	14	9.7	9	29.0
Other: ISK	N/A**	N/A**	1	3.2
Educational level*				
VMBO	37	25.7	15	48.4
HAVO	24	16.7	26	83.9
HAVO/VWO	5	3.5	N/A**	N/A**
VWO	78	54.2	27	87.1

* Grade and educational level indicate for students their current position and for teachers the grades and educational levels that they teach. Teachers could give multiple responses for these items.

** N/A = not applicable, these options were not included in the questionnaire, nor did participants add them in the open fields.

4.3 Instruments

Questionnaires

Student and teacher preferences were assessed using two similar types of online questionnaires that only varied in the paraphrasing of the questions (see Appendices A and B). The 26 items used in this study were part of a larger survey commissioned by educational publisher Noordhoff, that also covered students' viewing behaviour, their use of instructional videos and the rating of the publisher's own instructional videos.

The items for the present study were constructed to explore the preferences of students and teachers for multiple design features of instructional videos for mathematics (e.g., instructional media and human embodiment), and were developed based on the preceding theoretical framework. All items were assessed with bipolar endpoints (i.e., "extreme preference for the left design choice" and "extreme preference for the right design choice") and were rated on five-point bipolar scales. The items were categorized into four matrices to save space and to reduce the amount of reading, since all items in a matrix could be answered using the same opening statement (see Table 5). The operationalization and matrix assignment of all items is included in Appendix C.

A pilot study was conducted to test and refine the items. Reliability analysis showed a score of $\alpha = 0.456$. This low score was anticipated since the questionnaire items were designed to measure multiple constructs. Exploratory factor analysis confirmed this assumption. Because of the explorative design of this study, it was decided to maintain the questionnaire items but to be careful with the interpretation and generalization of the scores.

Table 5

Matrices and Opening Statements of Questionnaire Items

Matrix	Opening statements (translated from Dutch)
Instructor (INS)	"I/my students prefer instructional videos in which the instructor…"
Information display (INF)	"I/my students prefer instructional videos in which the information…"
Elements (ELE)	"I/my students prefer instructional videos that have the following elements…"
Other (OTH)	"I/my students prefer instructional videos…"

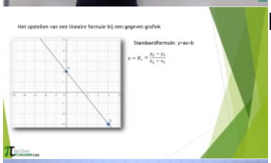
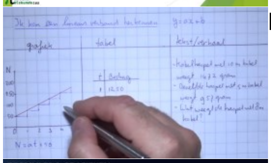
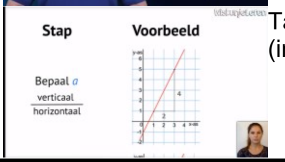
Student Focus groups and Teacher Interviews

The focus groups and interviews used a semi-structured design covering two topics: general use of instructional videos for mathematics (outside the scope of the present study) and preferences for design features of instructional videos for mathematics. For the latter topic, participants were asked to discuss the design features of five preselected videos. To start the discussion, the researcher asked two general questions after showing each video (i.e., "What did you like about this video?" and "What did you not like about this video?"). Consequently, more specific questions were asked based on the responses to ensure that multiple design elements of instructional videos were discussed (e.g., "What is your opinion about the presentation style?"). The interview guides containing the focus group and interview questions can be seen in Appendices D and E.

To allow for a good comparison, the videos used in the focus groups and interviews all covered the same mathematical topic (i.e., creating linear equations from a given graph), but varied in design characteristics (i.e., human embodiment and instructional media; see Table 6). The videos were selected using the following procedure. First, the ten YouTube channels with mathematical videos for secondary education that had the most subscribers were identified, because students and teachers are likely to come across these channels in their search for instructional videos on a mathematics subject. Next, for all ten channels the Dutch search term "lineaire formule opstellen bij een grafiek" (i.e., creating linear equations from a given graph) was used to find videos on this subject matter. For all channels, the video that best matched the subject was selected. Finally, the five videos that varied the most in design characteristics were used in the focus groups and interviews. From all five videos a section with a maximum of two minutes was shown that covered the main aim of the instruction.

Table 6

Index of Selected Videos for Focus Groups and Interviews

Nr.	Time frame	Screenshot	Human embodiment	Instructional medium	Source
1	3:34-5:34		Instructor	Whiteboard	YouTube: Math With Menno
2	0:00-1:39		None	Slides (PowerPoint)	YouTube: Onlinewiskundeles
3	2:13-4:13		Hand	Paper	YouTube: Marcel Eggen
4	0:00-1:51		Talking-head	Animation	YouTube: WiskundeAcademie
5	2:38-4:38		Talking-head (in frame)	Slides (Prezi)	YouTube: Hester Vogels

Note. This characterisation of videos is based on the index in Chorianopoulos (2018).

For the focus groups, a simple note sheet was constructed for students to write down their positive and negative impressions about the selected videos (see Appendix F). This element was added to the focus groups to help students structure their thoughts and to create enough input for the discussion following the viewing of the videos.

Audio Recordings

The audio of the focus groups and interviews was recorded with a voice recorder for the purpose of transcription and analysis. All participants, and at least one of the parents of students younger than sixteen years old, gave consent for these recordings in an online consent form (see Appendices G and H).

4.4 Procedure

Survey

The survey was constructed and distributed by the use of online survey platform Qualtrics. An email with an invitation to and information about the survey was sent to a sample of 600 teachers. The email included a link to the online teacher survey as well as a link to the online student survey. Besides filling out the teacher questionnaire themselves, the teachers were asked to direct their students to the survey during their classes within a time span of four weeks. The participants self-administered the survey by completing the online questionnaire. After two weeks, a reminder was automatically sent. Because of a low response of only 3.8%, presumably due to a combination of servers bouncing the e-mail, incorrect email addresses and low incentive because of the extra workload for teachers caused by the corona outbreak, another sample of 400 teachers was invited to participate in the survey. The deadline was extended for another two weeks to give them enough time to participate in the survey. After that period, the minimum of 30 teachers was reached with a response rate of 3.7%. All responses were automatically anonymized by the survey platform.

Student Focus groups and Teacher Interviews

A few weeks after the survey, the focus groups took place in two Dutch schools for secondary education. Prior to the start of the focus groups, students as well as at least one of their parents filled out an online consent form for participation in the research and the recording of the focus group audio. At the start of the focus groups, the researcher stated the goal of the meeting and double-checked whether all students agreed with the recording of the audio. Thereafter, the audio recording started and students were asked about their general use of instructional videos for mathematics. Consequently, students were asked to watch the predefined parts of the selected math videos. They were instructed that they could use a notes sheet while watching the videos to write down the positive and negative aspects they noticed about the design of the videos. After each video, students were asked to comment on the videos and to react to each other's statements. The duration of the focus groups was limited to 45 minutes, since this was the length of a lesson in both schools.

The same procedure was used for the teacher interviews, although these meetings were held online, due to the travel restrictions in the COVID-19 pandemic. An hour was scheduled for each interview.

4.5 Data Analysis

Survey

The bipolar items of the student and teacher questionnaires produced ordinal scores ranging from 1 (=extreme preference for left design feature) to 5 (=extreme preference for right design feature), with the score of 3 indicating 'no preference'. This quantitative data was analysed using IBM SPSS Statistics 25 in order to generate descriptive statistics about the preferences of students and teachers for the design of instructional videos, and to compare their responses. First, normality (i.e., Shapiro-Wilk test) and homogeneity of variance (i.e., Levene's test) were tested and revealed violations of these assumptions. Therefore, median scores and their corresponding interquartile range (IQR) were used to describe the preferences of students and teachers. Also, a non-parametric test (i.e., Mann-Whitney test) was used to compare the median scores of both actors. For these comparisons, the significance level was set at 0.05 and missing values were excluded pairwise.

The results are reported in three sections: minimize extraneous processing, manage essential processing, and fostering generative processing. The items were assessed to each section based on the instructional goal the design aspects are assumed to contribute to as displayed in the theoretical framework. Because of the low reliability of the questionnaires, all items were discussed individually and no sum scores were reported for these subscales.

Student Focus groups and Teacher Interviews

Qualitative content analysis was conducted on the data from the focus groups, to add to the findings from the questionnaires. The audio recordings of the focus groups were transcribed verbatim and subsequently coded using ATLAS.ti 9. A directed approach to content analysis was used, as described by Hsieh and Shannon (2005). First, three coding groups (i.e., extraneous, essential and generative processing) and fourteen initial coding categories (e.g., coherence) and their operationalizations were derived from the design principles and techniques discussed in the theoretical framework. Subsequently, the transcripts were read repeatedly and all text relevant to the design of instructional videos was divided into utterances. Each utterance contained a participant’s opinion about a design feature in a video. These utterances were then coded using the predetermined codes. Any text that could not be categorized with the initial coding scheme, because participants referred to other design features that were not yet included, was given a new code (e.g., instruction). Moreover, design features that were not mentioned in the focus groups were removed from the coding scheme (e.g., spatial contiguity). This coding process led to a final list of the predefined three predefined code groups and twelve codes (see Table 7). The findings from the content analysis are descriptively reported in the results section.

Table 7

Codebook Content Analysis Focus Groups and Interviews

Code Group	Code	Definition	Examples (translated from Dutch)
Extraneous processing	Signalling	The participant refers to the use of visual or verbal cues in the video.	“So just indicating with an arrow or a square (…), I really miss that here.”
	Coherence	The participant refers to the presence or absence of extraneous material in the video.	“He only shows what he is explaining.” “Not too many moving objects on-screen.”
	Temporal contiguity	The participant refers to the synchronization of words and graphics in the video.	“His explanation is of course a very nice one, which is completely synchronized with what he points at.”
Essential processing	Instruction	The participant refers to the instructional content of the video.	“That it is now clearly stated what the sum is.”
	Organization	The participant refers to the elements that structure the video.	“Really nice about this is that he briefly repeats how it works.”
	Pace	The participant refers to the pace of the instruction in the video.	“He was explaining something and when he was done with that the following was already showing.”
Generative processing	Multimedia	The participant refers to the use of a combination of narration and visuals in the video.	“That you not only need to pay attention to what the person is saying, but that it is mixed with (…) something you can see.”
	Instructional medium	The participant refers to the physical or digital presentation style used in the video.	“The advantage of a PowerPoint, it is easier to read than handwriting.”
	Visuals	The participant refers to the on-screen media used in the video, such as text and graphics. .	“This person is of course known for the perfect pictures (…). He has always done that well.”
	Narration	The participant refers to the voice or text of the narration.	“He explained with a clear voice.” “I thought he sounded confident.”
	Video length	The participant refers to the length of the video.	“I think that (...) the length of the video also should not be too long."
	Human embodiment	The participant refers to the presence or absence of a visible instructor in the video.	“Then you definitely know what he looks like (…). Because then you also know what kind of person it is.

5. Results

To answer the research questions concerning what characteristics of instructional videos students and their teachers in secondary mathematics education perceive as important, the data from the questionnaires, focus groups and interviews were analysed.

5.1 Minimize Extraneous Load

Survey

Students and teachers agreed on most design elements that can reduce extraneous load (see Table 8). A neutral background was preferred by 70.3% of students (N_s = 141, *Mdn* = 2.00) and 60.0% of teachers (N_t = 30, *Mdn* = 2.00). Moreover, 80.0% of teachers (N_t = 30, *Mdn* = 2.00) and 69.7% of students (N_s = 139, *Mdn* = 2.00) preferred no background music, and 83.3% of teachers (N_t = 30, *Mdn* = 2.00) as well as 62.3% of students (N_s = 143, *Mdn* = 2.00) preferred visual over verbal signalling. A Mann-Whitney test confirmed that there were no significant differences between students and teachers for background complexity (U = 1971.00, p = .536), the use of background music (U = 1996.50, p = .695), and signalling type (U = 1907.00, p = .317).

Furthermore, 77.4 % of teachers (N_t = 31, *Mdn* = 4.00) and 51.1% of students (N_s = 143, *Mdn* = 4.00) preferred information to become gradually visible. A Mann-Whitney test did show a significant difference between the median scores of both actors on this design feature, U = 1723.00, p = .045. The interquartile ranges show that most teachers (IQR = 0) agreed on this design aspect, whilst students were more divided (IQR = 2). Another significant difference was found for the preferences for the brevity of on-screen text, U = 1586.00, p = .022: 53.3% of teachers preferred key words over full sentences, whereas students showed no clear preference for one of these design options.

Table 8

Survey Results for Extraneous Processing

Design features	Students			Teachers		
	n_s	*Mdn*	*IQR*	n_t	*Mdn*	*IQR*
neutral vs. complex background	141	2.00	2.00 (1.00-3.00)	30	2.00	2.00 (1.00-3.00)
without vs. with background music	139	2.00	2.00 (1.00-3.00)	30	2.00	1.00 (1.00-2.00)
visual vs. verbal signalling	143	2.00	2.00 (1.00-3.00)	30	2.00	1.00 (1.00-2.00)
key words vs. full sentences	143	3.00	2.00 (2.00-4.00)	30	2.00	1.00 (2.00-3.00)
Information fully vs. gradually visible	143	4.00	2.00 (2.00-4.00)	31	4.00	0.00 (4.00-4.00)

Note. Items are bipolar scored (1 = extreme preference for left design choice, 2 = moderate preference for left design choice, 3 = no preference, 4 = moderate preference for right design choice, and 5 = extreme preference for right design choice).

Student Focus groups and Teacher Interviews

Most students and teachers referred to the use of visual cues in the videos. They especially liked the use of colours, frames and arrows in the fourth video. Moreover, the pointing of the finger and pen tip in the third video was perceived as useful for highlighting relevant material. The use of a pointer in digital presentations was perceived as less effective for this goal by some of the participants. One participant mentioned that he did not even noticed the pointer. Other visual cues that were mentioned included the use of hand gestures, dotted lines, flashing and underlining. The use of verbal cues was mentioned far less. Only one participant spoke about accentuating in the narration.

Students and teachers also referred to the coherence in the videos. Especially the set-up of the second video was perceived as incoherent. Many participants said that there was too much irrelevant information on screen. Moreover, other extraneous material they noticed included background noises such as rustle, clicking and the clearing of the instructor's throat. Further distractions they referred to were moving objects and background music.

The last topic that was discussed in the focus groups and interviews was the temporal contiguity of the information in the video. One teacher and some students argued that the visual information should be synchronized with the narrations so that the instruction is easy to follow and understand.

5.2 Manage Essential Processing

Survey

Students and teachers had different opinions on some design features that could help manage essential processing. Most teachers, 58.1% (N_t = 31, *Mdn* = 2.00) preferred non segmented videos (i.e., videos in one part instead of divided into chapters), whilst students showed no clear preference for the use of segmentation (N_s = 139, *Mdn* = 3.00). Similarly 86.7% of teachers (N_t = 30, *Mdn* = 4.00) preferred the use of summaries, whereas students (N_s = 141, *Mdn* = 3.00) showed no clear preference for this design feature. On the other hand, 54.3% of students (N_s = 140, *Mdn* = 4.00) preferred the use of an overview at the beginning of videos, whereas teachers (N_t = 31, *Mdn* = 3.00) showed no clear preference for this design choice. Furthermore, 76.0% of students (N_s = 142, *Mdn* = 5.00) preferred the use of reviews in videos, whilst teachers (N_t = 31, *Mdn* = 3.00) showed no clear preference for this design element. Only the differences for the use of summaries (U = 1143.00, $p < .001$) and reviews (U = 1046.00, $p < .001$) were found to be significant (see Table 9). The Mann-Whitney test showed no significant results for segmentation into chapters (U = 1926.00, p = .344) or the use of an overview (U = 2043.50, p = .597).

Students and teachers did agree on two design features that affect essential processing. Both actors showed no clear preference for spoken or written text (N_s = 144, *Mdn* = 3.00; N_t = 30, *Mdn* = 3.00), whilst 69.0% of teachers and 62.6% of students did prefer videos without pauses (N_s = 139, *Mdn* = 2.00; N_t = 29, *Mdn* = 2.00). There were no significant differences for text modality (*U* = 1768.00, *p* = .102) or the use of pauses (*U* = 1955.00, *p* = .791).

Table 9

Survey Results for Essential Processing

Design features	Students			Teachers		
	n_s	*Mdn*	*ÏQR*	n_t	*Mdn*	*IQR*
one part vs. chapters	139	3.00	3.00 (1.00-4.00)	31	2.00	2.00 (1.00-3.00)
without vs. with pauses	139	2.00	2.00 (1.00-3.00)	29	2.00	2.00 (1.00-3.00)
without vs. with overview	140	4.00	2.00 (3.00-5.00)	31	3.00	1.00 (3.00-4.00)
without vs. with review	142	5.00	1.00 (4.00-5.00)	31	3.00	1.00 (3.00-4.00)
without vs. with summary	141	3.00	1.00 (3.00-4.00)	30	4.00	1.00 (4.00-5.00)
spoken vs. written text	144	3.00	2.00 (2.00-4.00)	30	3.00	1.00 (3.00-4.00)

Note. Items are bipolar scored (1 = extreme preference for left design choice, 2 = moderate preference for left design choice, 3 = no preference, 4 = moderate preference for right design choice, and 5 = extreme preference for right design choice).

Student Focus groups and Teacher Interviews

Although the instructional content of the videos was outside the scope of this study, this was often the first topic students as well as teachers focused on after watching the videos. Both actors mentioned repeatedly that the instruction should be “clear”. In particular, the instruction of the procedures (or steps) combined with some conceptual knowledge was considered important. Other subjects regarding the instruction in the videos that were often mentioned included the difficulty of the worked examples, the clarity of the problem statement and the extensiveness of the instruction. Moreover, one teacher stressed the importance of using mathematical terms and equations correctly. The teachers disagreed about embedding the problem statement in a meaningful context. The teacher who currently teaches VMBO was in favour of the use of context for her students, whilst the teacher who currently teaches HAVO and VWO argued that his students were able to apply the knowledge from worked examples in instructional videos to similar situations without the need of a context.

Both students and teachers also referred to elements that could be useful to structure the content of the video. Especially a good introduction of the problem statement was often mentioned. Moreover, a short review of prior knowledge at the start of a video was considered useful by some participants. One teacher argued that this leads to students experiencing success which might motivate them for the remainder of the instruction.

5.3 Foster Generative Processing

Survey

For most of the design features that could foster generative processing, students as well as teachers showed no clear preferences (see Table 10). This was the case for instructor gender (N_s = 143, *Mdn* = 3.00; N_t = 31, *Mdn* = 3.00), age (N_s = 143, *Mdn* = 3.00; N_t = 30, *Mdn* = 3.00), and speaking rate (N_s = 143, *Mdn* = 3.00; N_t = 30, *Mdn* = 3.00). Moreover, they showed no preference for the use of animations or drawings (N_s = 141, *Mdn* = 3.00; N_t = 29, *Mdn* = 3.00), guiding questions (N_s = 141, *Mdn* = 3.00; N_t = 30, *Mdn* = 3.00), interpolated questions (N_s = 141, *Mdn* = 3.00; N_t = 30, *Mdn* = 3.00), or subsequent exercises (N_s = 141, *Mdn* = 3.00; N_t = 30, *Mdn* = 3.00). The Mann-Whitney test confirmed that there were no significant differences between students and teachers for instructor gender (U = 2126.00, p = .919), speaking rate (U = 1969.00, p = .446), type of visuals (U = 2041.00, p = .988), nor for the use of guiding questions (U = 1893.50, p = .353), interpolated questions (U = 1949.00, p = .487), and subsequent exercises (U = 2024.00, p = .704).

Table 10

Survey Results for Generative Processing

Design features	Students			Teachers		
	n_s	*Mdn*	*IQR*	n_t	*Mdn*	*IQR*
handwritten vs. typed text	141	4.00	2.00 (3.00-5.00)	31	3.00	2.00 (3.00-5.00)
animations vs. drawings	141	3.00	2.00 (2.00-4.00)	29	3.00	1.00 (2.50-3.50)
short vs. long duration	140	3.00	1.00 (2.00-3.00)	31	2.00	1.00 (2.00-3.00)
physical vs. digital presentation	143	3.00	2.00 (2.00-4.00)	31	3.00	2.00 (2.00-4.00)
audible vs. visible instructor	143	4.00	2.00 (3.00-5.00)	30	4.00	2.00 (3.00-5.00)
male vs. female instructor	143	3.00	0.00 (3.00-3.00)	30	3.00	0.00 (3.00-3.00)
young vs. old instructor	143	3.00	1.00 (3.00-4.00)	30	3.00	0.00 (3.00-3.00)
slow vs. fast speaking rate	143	3.00	1.00 (2.00-3.00)	30	3.00	1.00 (2.00-3.00)
enthusiastic vs. serious tone	143	2.00	1.00 (2.00-3.00)	30	2.00	1.00 (2.00-3.00)
personal vs. formal communication style	144	2.00	2.00 (1.00-3.00)	30	2.00	2.00 (1.00-3.00)
without vs. with guiding questions	141	3.00	2.00 (2.00-4.00)	30	3.00	0.25 (2.75-3.00)
without vs. with interpolated questions	141	3.00	2.00 (2.00-4.00)	30	3.00	1.25 (2.75-4.00)
pauses automatically vs. manually	138	5.00	2.00 (3.00-5.00)	30	4.00	1.00 (4.00-5.00)
without vs. with subsequent exercises	141	3.00	2.00 (2.00-4.00)	30	3.00	1.25 (2.75-4.00)

Note. Items are bipolar scored (1 = extreme preference for left design choice, 2 = moderate preference for left design choice, 3 = no preference, 4 = moderate preference for right design choice, and 5 = extreme preference for right design choice).

Although both actors also showed no clear preference for instructional medium (N_s = 143, *Mdn* = 3.00; N_t = 31, *Mdn* = 3.00), 68,8 % of students (N_s = 141, Mdn = 4.00) did prefer typed text over handwritten text, whilst teachers (N_t = 31, Mdn = 3.00) showed no clear preference for this design feature. This difference was found to be significant, U = 1672.50, p = .031, whereas there were no significant results found for instructional medium (U =

1845.50, p = .134). Another difference was found for video length. Whereas 54,8% of teachers preferred videos with a duration around three minutes, most students preferred the length of videos to be around six minutes (N_s = 140, *Mdn* = 3.00; N_t = 31, *Mdn* = 2.00). This difference was not significant (*U* = 1719.50, *p* = .052).

Furthermore, a visible instructor was preferred by 60,0% of teachers (N_t = 30, *Mdn* = 4.00) and 56,7% of students (N_s = 143, *Mdn* = 4.00). Moreover, 70,0% of teachers (N_t = 30, *Mdn* = 2.00) and 66,7% of students (N_s = 144, *Mdn* = 2.00) preferred this instructor to use a personal communication style. Likewise, an enthusiastic tone was preferred over a serious tone by 70,0% of teachers (N_t = 30, *Mdn* = 2.00) and 59,5% of students (N_s = 143, *Mdn* = 2.00. There were no significant results for instructor's visibility (*U* = 2131.50, *p* = .955), communication style (*U* = 2114.50, *p* = .848), and tone (*U* = 1973.50, *p* = .469).

Finally, both 86,7% of teachers and 73,9% of students preferred manual pauses over automatic pauses. Although the average scores for students (N_s = 138, *Mdn* = 5.00) were higher than those of teachers (N_t = 30, *Mdn* = 4.00), this difference was not significant (*U* = 2045.00, *p* = .911).

Student Focus groups and Teacher Interviews

Participants referred the most to the instructional media used in the videos. The first video with the instructor using a whiteboard was received well. Teacher and students argued that this style of presentation works because it is recognisable and it fits the need for students to write down the intermediate steps as they are also supposed to do in tests, especially in higher grades. Important boundary conditions of this physical presentation style that were mentioned are the readability of the handwriting as well as the instructor not standing in front of the information or turned away from the camera. On the other hand, digital presentation styles were seen as more appealing and organized, in particular in the fourth video. Another benefit of digital presentations that was mentioned is the possibility to include animations as well as all sorts of visual cues. A downside that was often mentioned was that the information in digital videos appears in a faster pace, which makes it harder for students to write along. One student stated that the best solution would be a combination of a digital presentation with the basic information and graphics clearly presented and the instructor writing the intermediate steps by hand.

The presence of the instructor in the video was another topic that was often discussed. Most students argued that they like to know what the instructor looks like because it makes the instructor more human and the video more personal. One student stated that otherwise it would be the same as listening to a robot. Moreover, some students stated that it helps them to pay attention. Another benefit of a visible instructor was that he or she could point things out, although some hand gestures were referred to as distracting. One teacher mentioned that a visible instructor makes a presentation less boring. A downside that was often mentioned is that a visible instructor distracts students from essential material. Especially when the image of the instructor was found to have no clear function, for example the instructor in a frame in the fifth video was referred to as a moving passport photograph, students argued that the image of the instructor could be left away. In the fourth video, a visible instructor introduced the problem statement whereafter he was only audible during the instruction. For most participants this was a good compromise, although one teacher found him not visible enough.

The narration was also a recurring topic in the focus groups and interviews, in particular the instructor’s speaking rate, audibility and the use of filler words. The speaking rate of most instructors was perceived as good, only the fourth instructor was speaking too fast for some students. The third instructor was perceived as less audible than the other instructors. One student added that the instructor’s voice in the first video was monotone and should be more energetic as if he talks to a real class. Moreover, the use of filler words (e.g. “um”, “uh”) made the narrator seen as less confident and less professional. Furthermore, one teacher argued that a personal communication style might help novice students, but expert learners might find this style childish. Also the text of the narration was mentioned by some participants. Instructors should use language that is easy to follow and mathematical correct. Opinions about the repetition of information differed.

Students also stressed the use of visuals to complement the information in the narration. Some students argued that animations could make instructional videos more appealing as well as clearer. Moreover, some students stated that (background) colours and font size should be chosen well to make the information stand out and readable.

Only one participant, the female teacher, spoke about the length of the video. For her to use instructional videos in her lessons, the duration should be three minutes at most, whilst videos to use outside her class could be a bit longer.

6. Discussion

The aim of the current study was to explore to what extent general research-based design guidelines for instructional videos match the preferences of students and teachers in secondary mathematics education. To answer this research question, the insights from the theoretical framework were compared with the results from the survey, student focus groups and teacher interviews.

The results of this study indicate that many of the research-based design guidelines also apply to the design of instructional videos for secondary mathematics education, since both students and teachers prefer their use in instructional videos for this subject. First, the participants liked coherence in the videos, by showing a preference to exclude extraneous material in the form of a complex background and background music. This was confirmed by participants in the focus groups and interviews, who referred to other extraneous material, such as noise, clicking sounds and moving objects, as distracting. Participants also agreed that essential information should become gradually visible, synchronized with the narration. These results are consistent with the coherence principle and the temporal contiguity principle (Mayer & Fiorella, 2014).

Both students and teachers also recognized the advantage of signalling by showing a preference for the use of visual signalling. The cueing of visual elements in instructional videos (e.g., using arrows or colour coding) has been proven to guide learners' attention to relevant elements of the video and thereby reducing the extraneous processing of less relevant information (Van Gog, 2014). However, the study of Xie et al. (2018) showed that visual signalling alone does not necessarily improve learning outcomes on retention or transfer tests. Synchronized auditory cueing is needed to achieve deeper processing (Xie et al., 2018). Therefore, coordinated dual-modality cueing is recommended in the design of instructional videos for secondary math education.

Moreover, both students and teachers preferred a visible instructor, although the risk of distracting students was also recognized by participants in the focus groups. These findings are consistent with earlier studies that found motivational effects for instructor presence (e.g., Wang and Antonenko, 2017), as well as with studies that found a visible instructor to be distracting (e.g., Van Wermeskerken et al., 2018). Focus group participants found a visible instructor at the beginning of the video sufficient to give students a personal feeling, when followed by instructor's absence during the actual instruction to prevent students from being distracted. Another solution to avoid distraction is to make sure the instructor is functional throughout the whole video, for example by writing, pointing or gazing, as was also argued by Ouwehand et al. (2015). Additionally, the participants liked the instructor to use a personal and enthusiastic communication style, which is in line with the personalization principle and previous studies by Ginns et al. (2013) and Guo et al. (2014). The gender of the instructor did not seem to be important for students nor teachers. Similar results for gender were found in a study of Hoogerheide et al. (2018).

The results for video length show that both students and teachers prefer videos with a duration of three to six minutes. This finding is consistent with the recommendation from earlier studies that videos should be kept short (Guo et al., 2014; Kim et al., 2014; Ten Hove & Van der Meij, 2015). Studies from Guo et al. (2014) and Kim et al. (2014) showed that student engagement dropped significantly when video length was longer than six minutes. However, the optimal length of instructional videos might depend on the instructional goal, as was argued by one of the teachers. When teachers use instructional videos in a classroom setting, the videos have to be less elaborate since teachers can provide extra information on the spot. In contrast, students who use videos outside of the classroom might need additional information and examples. Further research is needed to check this assumption.

Furthermore, both students and teachers preferred some kind of structural elements in the videos, although their opinions seem to differ with regard to what solution best fits the students' needs. Students preferred pre-training in the form of an overview or a review, whilst teachers thought a summary at the end of the video would best serve their students. A clear introduction of the problem statement was added as structural element by both students and teachers in the focus groups and interviews. The use of these kind of structural elements in instructional videos helps learners to process the information in the video in different ways (Mayer & Pilegard, 2014; Van der Meij & Van der Meij, 2016). Pre-training techniques, such as reviews and overviews, presented at the start of an instruction provide learners with prior knowledge that reduces the amount of processing needed to understand the instruction (Mayer & Pilegard, 2014), whereas a summary at the end of the instruction can enhance retention by structuring the information in a clear procedural way (Van der Meij & Van der Meij, 2016). Since mathematics is a complex subject with high levels of element interactivity, instructional techniques for managing this high intrinsic load are critical to leave enough cognitive capacity available for generative processing. This would favour pre-training techniques over summaries for this and other complex knowledge domains, whereas design features that foster generative processing might better fit less complex subjects. It would be interesting for future research to compare which (combination of) structural elements enhance student engagement and learning from instructional videos the most for subjects with different levels of complexity.

On the other hand, the findings from this study suggest that the design of instructional videos for secondary math education might benefit from different design guidelines than the general design guidelines for multimedia learning. First, mathematical videos seem to be more effective with relatively more on-screen text than videos designed for other subjects. Students as well as teachers showed no clear preference for either spoken or written words in the survey. Moreover, a combination of narrated and visual display of intermediate steps was stressed in the focus groups. These remarkable findings contradict the redundancy principle, which states that redundant on-screen text should be avoided (Kalyuga & Sweller, 2014). Support for the findings in this study was given by Clark and Mayer (2016). They argue that words sometimes should remain available for the learner for memory support, for example in the case of mathematical formulas because of their complexity. They also propose that key words that identify the steps of a procedure may be presented as on-screen text and highlighted as each step is illustrated in the animation and discussed in the narration (Clark & Mayer, 2016). These findings lead to the recommendation that mathematical formulas, equations and intermediate steps are presented in keywords as on-screen text in instructional videos for mathematics.

Another remarkable finding from this study has to do with the pace of instructional videos for mathematics. Although earlier studies showed that students engage more with videos with fast speaking instructors (Guo et al., 2014; Ten Hove & Van der Meij, 2015), the current study pinpointed a possible exception for instructional videos in secondary mathematics education. Whereas survey participants showed no clear preference for slow or fast speaking instructors, focus groups participants argued that the pace of mathematics videos should enable students to write along with the worked examples, especially in higher grades. This would require a lower speaking rate than would be recommended from the findings in earlier studies (Guo et al., 2014; Ten Hove & Van der Meij, 2015). However, Guo et al. (2014) did also find that videos with slow speaking instructors (48–130 wpm), who simultaneously wrote on a blackboard, contributed to higher engagement than mid-speed videos (145–165 wpm). The benefits of seeing the instructor's writing on students' engagement and learning would also be in line with the dynamic drawing principle described by Mayer et al. (2020). Further research should clarify what the ideal pace is for instructional videos for mathematics to enable students to write along, without making the instruction boring.

Other results from the survey did not match the theoretical design guidelines about segmentation. First, both actors preferred videos without pauses, although pauses give students extra time to take in the information whilst also highlighting the structure of the key concepts (Spanjers et al, 2012). Likewise, teachers preferred videos to be delivered in one part over the use of chapters, whilst students had mixed opinions regarding this design aspect. A possible explanation is that the use of chapters and pauses in instructional videos for secondary mathematics education is not common. Consequently, participants might not be familiar with the benefits of these kinds of segmentation for essential processing. However, earlier studies show that novice learners rarely pause videos (Biard, Cojean & Jamet, 2018) and do not have enough knowledge to segment a video in meaningful chunks (Wouters et al., 2007). These insights, alongside the wish of participants for learner-control over the pace over the video, lead to the recommendation to combine predefined chapters with learner control over the continuation of the video.

For other design features, the results from the survey were less evident. For example, the results indicate that instructor characteristics, such as gender and age, do not have to be taken into account in the design of instructional videos. Whereas the results for gender confirm research of Hoogerheide et al. (2018), the results for instructor's age seem to contradict the recommendation of Hoogerheide et al. (2016) that older instructors are favourable, because they are more often seen as experts than peer instructors. The focus groups and interviews, however, did reveal other aspects of the instructor that teachers and students might see as less experienced or confident, such as the use of filler words and insufficient preparation. The preference for cohesive explanations is line with earlier research of Lachner and Nückles (2015), who showed that experts' explanations can be considered as a valuable scaffold for engaging novices in a meaningful construction of knowledge, due to their high global cohesion. Altogether, these findings could lead to the conclusion that the instructor's age is less important for students' learning and engagement than other instructor's qualities, such as high-cohesive explanations. However, the survey results for instructor's age should be interpretated carefully, because of the way the item was constructed. The middle point between a peer instructor and a much older instructor could besides being explained as no preference, also been interpretated as a midway between these extreme options. Because of this ambiguity, the results on instructor age could not be generalised. Therefore, more research is needed to clarify whether preferences for instructor age are indeed correlated to the quality of the instruction.

The survey results for instructional medium also showed no clear preference for either digital or physical presentation, although the majority of students did prefer typed over handwritten text. The focus groups and interviews confirmed these mixed findings and showed that some participants liked the clarity and possibilities that digital presentation styles offer, whilst other participants found physical presentation styles to be more engaging and better paced. A possible explanation for these mixed findings could be that the instructional needs of students depend on their memory capacity, their cognitive and metacognitive strategies, and their level of prior knowledge (Mayer, 2014a). To check this assumption, further research should clarify whether preferences for instructional medium depend on related student characteristics such as age, grade and level of education.

Moreover, students and teachers seemed to have no clear preference for the use of either animations or drawings. However, these findings could also be explained as that the preferred type of visuals depends on the goal of the visual information. This would be in line with the recommendations of Clark and Mayer (2016) that animations are best used to visualize hands-on procedures or to serve an interpretive function, whilst static visuals, such as drawings, are best suited to illustrate conceptual information. Another possible explanation is that the results for instructional medium were mixed, consequently leading to mixed results for animations (digital) versus drawings (physical). Additional research is required to find out what use of visuals best fits the needs of students in secondary mathematics education.

Furthermore, teachers and students showed no preference for design features that enhance active learning. Although several studies recommended the use of guiding questions (Lawson et al., 2006; Lawson et al., 2007), interpolated questions (Kovacs, 2016;

Szpunar et al., 2013), or subsequent exercises (MacHardy & Pardos, 2015), both students and teachers did not prefer the use of these design features in the survey nor did they mention any of those in the focus groups and interviews. One explanation could be that the participants were not familiar with these design features and their benefits. None of the mathematics videos that were encountered during the selection process for the qualitative part of this study consisted of even one of these elements. Another explanation could be that there is no need to use additional activating design features, since students are already active by writing along with the worked examples. However, the latter explanation is considered less likely since the results of the survey indicate that the participants did not dislike these design features.

Finally, the findings of the survey show that students and teachers generally agree on the design of instructional videos for secondary math education. For only five out of 25 questionnaire items a significant difference was found. For four of these items (i.e., use of on-screen text, reviews, summaries, and handwritten versus typed text) one of the two actors preferred a design feature, whilst the other group showed no clear preference. In the other case (i.e., information fully versus gradually visible), the density of the preference differed. There were no cases in which students and teachers preferred opposite design features. These findings lead to the conclusion that the overall agreement between both actors was high.

6.1 Limitations

This study was aimed to explore and to compare the preferences of students and teachers for instructional mathematics videos in secondary education with research-based design guidelines. A combination of quantitative and qualitative research was conducted to provide deeper insight in the preferences of the population. Nonetheless, a few limitations are worth mentioning to guide future research.

First, this study focused on self-reported preferences of students and teachers, which are susceptible to response bias (Cohen et al., 2011). Consequently, the instructional techniques favoured by the participants in this study might not actually lead to improved student' learning and engagement. To validate these findings, future research should examine actual student' behaviours and reactions while using instructional videos for mathematics and testing the effects of the instructional videos on learning. Additionally, an analysis of viewing behaviour of popular mathematics videos on YouTube similar to the analysis conducted by Ten Hove and Van der Meij (2015) could provide more insight in the design features that lead to student engagement.

Moreover, the survey used in this study was constructed to obtain a general idea of the preferences of students and teachers on all sorts of design features for instructional videos. Consequently, the questionnaires did not measure a single construct, which was confirmed by reliability testing and factor analysis. The reliability of this study is also reduced because no intercoder reliability could be calculated for the qualitative part of the study due to the lack of a second coder. Further research is recommended to verify the findings of this study, for example by using more reliable instruments that use more items to target specific design components and by the use of multiple coders.

Another limitation of the survey was that participants had to choose between different design features for instructional videos without showing actual footage of the different options. Example footage of the different design features was not included in the survey to keep it short and manageable. However, participants might not have had enough prior knowledge of different design features needed to answer all items. Therefore, the survey might have measured the participants' familiarity with the provided options instead of their actual preference. To overcome this threat to the validity of the outcomes, actual footage of mathematical videos was included in the consequent focus groups and teacher interviews, which confirmed the outcomes of the survey for most design features. For future research it is recommended to include example footage of different design features in the survey for more reliable outcomes.

Furthermore, the videos used in the qualitative part of the study were the same for all grades and educational levels. Therefore, some students already mastered the content whilst others were novices. Moreover, by showing multiple videos covering the same subject in the same order, participants may have mastered the content while watching, therefore becoming more expert towards the final videos. Although both issues might have influenced the participants' perceptions, they did not seem to have a major impact on the reliability of the data, since participants' preferences did not change during the sessions and were generally in line with the findings from the survey. However, future studies should consider varying levels of content and order of the instruments used to increase reliability.

Finally, many of the theoretical design guidelines discussed in this study are especially beneficial for novice learners, whilst being less effective or even hindering learning for more knowledgeable learners (Kalyuga, 2014). This expertise reversal effect is for example found for segmentation (Spanjers et al, 2012). To overcome this problem, the content of instructional videos should be tailored to levels of learners' expertise by gradually replacing high-structured instructional procedures and formats with low-structured instructions as the knowledge level increases (Kalyuga, 2014). Additionally, an interesting direction for future research would be to compare the preferences of students and teachers in different levels and grades of education. This would provide more insight in what design guidelines fit different levels of learners' expertise best.

7. Conclusion

The current study examined to what extent general research-based design guidelines for instructional videos do or do not match the needs of students in secondary mathematics education displayed by students' and teachers' preferences. The study was designed to add to the research base on multimedia learning in three ways: 1) by focusing on the design of instructional videos for secondary education, in contrast to earlier research that mainly focused on higher education, 2) by confirming the usability of a broad range of research-based design guidelines for the complex subject of mathematics, and 3) by comparing these guidelines for instructional videos with the preferences of the end users, namely students and teachers.

The findings of this study led to promising insights. First, the present study confirmed many of the research-based design guidelines for instructional videos, whilst also pinpointing possible exceptions for the subject of mathematics in secondary education. These findings show that effective design of instructional videos partly depends on the subject being taught and the age of the learners. Additionally, some remarkable and inconclusive results led to valuable recommendations for further research.

The findings of this study are also valuable for educational professionals. By reviewing an extensive number of empirical studies and combining the obtained research-based design guidelines with the findings from quantitative and qualitative research, educational publishers and teachers are provided with new insights in how to design and select future instructional videos for mathematics to best serve students' learning and engagement in secondary education. Moreover, the study revealed promising instructional techniques that are yet to be used in instructional videos for secondary mathematics education. By implementing these findings, future instructional videos will be better capable to engage students in learning how to solve complex mathematical problems.

Altogether, the current study gave more insight in effective design guidelines for instructional videos, in particular for secondary mathematics education. This contribution is especially important with the actual increasing need for well-designed instructional videos.

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9. Appendices

Appendix A: Student Survey (Dutch)

Vragenlijst instructievideo's wiskunde - leerlingen

Start of Block: Inleiding

Beste leerling,

Allereerst wil ik je hartelijk bedanken dat je de vragenlijst wilt invullen. Mijn naam is Annelies Kolthof en ik ben student aan de Universiteit van Twente en stagiaire bij Noordhoff. Voor mijn afstuderen doe ik onderzoek naar het gebruik, de vindplaats en de waardering van instructievideo's voor wiskunde.

Het doel van het onderzoek is om inzicht te krijgen in wat jullie belangrijk vinden bij instructievideo's om de kwaliteit ervan te kunnen optimaliseren.

De vragenlijst zal ongeveer 10 minuten in beslag nemen. Er zal vertrouwelijk worden omgegaan met je gegevens en de antwoorden zullen geheel anoniem worden verwerkt. Mocht je nog vragen hebben over het onderzoek, neem dan contact met mij op via a.a.kolthof@student.utwente.nl.

Nogmaals hartelijk dank voor je deelname aan dit onderzoek.

Met vriendelijke groet,
Annelies Kolthof

Ga je ermee akkoord dat je persoonlijke gegevens worden verwerkt zoals hierboven beschreven? Klik op ja om verder te gaan naar de vragenlijst.
o Ja
o Nee

Skip To: End of Survey If Ga je ermee akkoord dat je persoonlijke gegevens worden verwerkt zoals hierboven beschreven? Klik... = Nee

Start of Block: Ontwerpvoorkeuren

De volgende vragen gaan over jouw voorkeuren voor het ontwerp van de instructievideo's voor wiskunde. Geef aan in hoeverre je naar één van de twee opties neigt. Kies het middelste bolletje als je geen voorkeur voor een van beide opties hebt of als jouw voorkeur een mix is van beide opties.

Instructievideo's spreken mij het meest aan als de docent in de video ...

	1	2	3	4	5	
een man is	○	○	○	○	○	een vrouw is
van mijn leeftijd is	○	○	○	○	○	veel ouder is dan ik
alleen te horen is	○	○	○	○	○	zichtbaar in beeld is
mij persoonlijk aanspreekt (bijvoorbeeld	○	○	○	○	○	"Je ziet hier de driehoek ABC")
langzaam praat	○	○	○	○	○	snel praat
op enthousiaste toon praat	○	○	○	○	○	op serieuze toon praat

Page Break

Instructievideo's spreken mij het meest aan als de informatie ...

	1	2	3	4	5	
verteld wordt	○	○	○	○	○	in tekstvorm in beeld komt
is geschreven	○	○	○	○	○	is getypt
op bord of papier geschreven of getekend wordt	○	○	○	○	○	in een PowerPoint wordt getoond
vooraf zichtbaar is	○	○	○	○	○	geleidelijk in beeld komt
in steekwoorden in beeld is	○	○	○	○	○	in volledige zinnen in beeld is
indien belangrijk met pijlen en kleuren wordt benadrukt	○	○	○	○	○	indien belangrijk met de stem wordt benadrukt

Page Break

Instructievideo's spreken mij het meest aan als de video de volgende onderdelen bevat ...

	1	2	3	4	5	
geen samenvatting aan het eind	○	○	○	○	○	wel een samenvatting aan het eind
geen kijkvragen vooraf	○	○	○	○	○	wel kijkvragen vooraf (bijvoorbeeld
geen vragen tijdens de video	○	○	○	○	○	wel vragen tijdens de video
geen vragen achteraf	○	○	○	○	○	wel vragen achteraf
geen overzicht vooraf	○	○	○	○	○	wel een overzicht vooraf
geen terugblik naar de vorige les	○	○	○	○	○	wel een terugblik naar de vorige les

Page Break

Instructievideo's spreken mij het meest aan als de video …

	1	2	3	4	5	
korter dan 1 minuut duurt	○	○	○	○	○	langer dan 12 minuten duurt
uit één deel bestaat	○	○	○	○	○	uit meerdere korte delen ("hoofdstukken") bestaat
geen pauzes bevat	○	○	○	○	○	wel pauzes bevat
automatisch pauzeert	○	○	○	○	○	op zelfgekozen momenten gepauzeerd kan worden
computeranimaties bevat	○	○	○	○	○	tekeningen bevat
een neutrale achtergrond bevat	○	○	○	○	○	een opvallende achtergrond bevat
geen achtergrondmuziek bevat	○	○	○	○	○	wel achtergrondmuziek bevat

End of Block: Ontwerpvoorkeuren

Appendix B: Teacher Survey (Dutch)

Vragenlijst instructievideo's wiskunde - docenten

Start of Block: Inleiding

Beste docent,

Allereerst wil ik u hartelijk bedanken dat u de vragenlijst wilt invullen. Mijn naam is Annelies Kolthof en ik ben student aan de Universiteit van Twente en stagiaire bij Noordhoff. Voor mijn afstuderen doe ik onderzoek naar het gebruik, de vindplaats en de waardering van instructievideo's voor wiskunde.

Het doel van het onderzoek is om inzicht te krijgen in wat docenten en leerlingen belangrijk vinden bij instructievideo's om de kwaliteit ervan te kunnen optimaliseren.
De vragenlijst zal ongeveer 10 minuten in beslag nemen. Er zal vertrouwelijk worden omgegaan met uw gegevens en de antwoorden zullen geheel anoniem worden verwerkt. Mocht u nog vragen hebben over het onderzoek, neem dan contact met mij op via a.a.kolthof@student.utwente.nl.

Nogmaals hartelijk dank voor uw deelname aan dit onderzoek.

Met vriendelijke groet,
Annelies Kolthof

Gaat u ermee akkoord dat uw persoonlijke gegevens worden verwerkt zoals hierboven beschreven? Klik op ja om verder te gaan naar de vragenlijst.

o Ja
o Nee

Skip To: End of Survey If Gaat u ermee akkoord dat uw persoonlijke gegevens worden verwerkt zoals hierboven beschreven? Kli... = Nee

Start of Block: Ontwerpvoorkeuren

De volgende vragen gaan over uw voorkeuren voor het ontwerp van de instructievideo's voor wiskunde. Geef aan in hoeverre u naar één van de twee opties neigt. Kies het middelste bolletje als u geen voorkeur voor één van beide opties heeft of als uw voorkeur een mix van beide opties is.

Instructievideo's spreken mijn leerlingen het meest aan als de docent in de video ...

	1	2	3	4	5	
een man is	○	○	○	○	○	een vrouw is
van hun eigen leeftijd is	○	○	○	○	○	veel ouder is dan henzelf
alleen te horen is	○	○	○	○	○	zichtbaar in beeld is
hen persoonlijk aanspreekt (bijvoorbeeld	○	○	○	○	○	"Je ziet hier de driehoek ABC")
langzaam praat	○	○	○	○	○	snel praat
op enthousiaste toon praat	○	○	○	○	○	op serieuze toon praat

Page Break

Instructievideo's spreken mijn leerlingen het meest aan als de informatie ...

	1	2	3	4	5	
verteld wordt	○	○	○	○	○	in tekstvorm in beeld komt
is geschreven	○	○	○	○	○	is getypt
op bord of papier geschreven of getekend wordt	○	○	○	○	○	in een PowerPoint wordt getoond
vooraf zichtbaar is	○	○	○	○	○	geleidelijk in beeld komt
in steekwoorden in beeld is	○	○	○	○	○	in volledige zinnen in beeld is
indien belangrijk met pijlen en kleuren wordt benadrukt	○	○	○	○	○	indien belangrijk met de stem wordt benadrukt

Page Break

Instructievideo's spreken mijn leerlingen het meest aan als de video de volgende onderdelen bevat ...

	1	2	3	4	5	
geen terugblik naar de vorige les	○	○	○	○	○	wel een terugblik naar de vorige les
geen kijkvragen vooraf	○	○	○	○	○	wel kijkvragen vooraf (bijvoorbeeld
geen vragen tijdens de video	○	○	○	○	○	wel vragen tijdens de video
geen vragen achteraf	○	○	○	○	○	wel vragen achteraf
geen overzicht vooraf	○	○	○	○	○	wel een overzicht vooraf
geen samenvatting aan het eind	○	○	○	○	○	wel een samenvatting aan het eind

Page Break

Instructievideo's spreken mijn leerlingen het meest aan als de video …

	1	2	3	4	5	
korter dan 1 minuut duurt	○	○	○	○	○	langer dan 12 minuten duurt
uit één deel bestaat	○	○	○	○	○	uit meerdere korte delen ("hoofdstukken") bestaat
geen pauzes bevat	○	○	○	○	○	wel pauzes bevat
automatisch pauzeert	○	○	○	○	○	op zelfgekozen momenten gepauzeerd kan worden
computeranimaties bevat	○	○	○	○	○	tekeningen bevat
een neutrale achtergrond bevat	○	○	○	○	○	een opvallende achtergrond bevat
geen achtergrondmuziek bevat	○	○	○	○	○	wel achtergrondmuziek bevat

End of Block: Ontwerpvoorkeuren

Appendix C: Operationalization of Questionnaire Items

Instructional goal	Bipolar items (translated from Dutch)	Mat.*
Minimize extraneous processing (N=4)	neutral vs. remarkable background	OTH
	without vs. with background music	OTH
	information fully vs. gradually visible	INF
	visual vs. verbal signalling	INF
	key words vs. full sentences	INF
Manage essential processing (N=9)	one part vs. chapters	OTH
	without vs. with pauses	ELE
	without vs. with review	ELE
	without vs. with overview	ELE
	without vs. with summary	ELE
	spoken vs. written text	INF
Foster generative processing (N=13)	short (1 min.) vs. long (12 min.) duration	OTH
	physical vs. digital presentation	INF
	handwritten vs. typed text	INF
	animations vs drawings	OTH
	audible vs. visible instructor	INS
	male vs. female instructor	INS
	young vs. old instructor	INS
	low vs. high speaking rate	INS
	enthusiastic vs. serious communication style	INS
	personal vs. formal communication style	INS
	without vs. with guiding questions	ELE
	without vs. with subsequent exercises	ELE
	without vs. with interpolated questions	ELE
	automatically vs. manually pauses	OTH

*Mat. refers to the matrix an item is assigned to in the questionnaire (INS = instructor characteristics, INF = information display, ELE = elements, OTH = other items).

Appendix D: Interview Guide for Student Focus Groups (Dutch)

Voorbereide vragen focusgroepen leerlingen

1. **Toelichting doel van onderzoek en audio-opname**

2. **Vragen naar algemeen gebruik wiskundevideo's (max 5 min.)**
   Deelnemers vragen naar hun gebruik van instructievideo's in het algemeen.
   - Kijk je wel eens wiskundevideo's? Zo ja, hoe vaak? Zo nee, waarom niet?
   - Waarom kijk je wiskundevideo's?
   - Op welk moment kijk je wiskundevideo's? Bijvoorbeeld tijdens de les, huiswerk, voorbereiding op toets?
   - Hoe kom je aan de video's? Bijvoorbeeld via docent, methode of zoek je ze zelf?
   - Waar let je op bij het kiezen van een video?
   - Heb je een favoriete aanbieder?
   - Maakt je docent wel eens wiskundevideo's?

3. **Vragen naar mening over verschillende soorten video's (*5 ingekorte video's tonen)* (max 30 min.)**
   - Wat spreekt je aan bij deze video?
   - Wat vind je minder goed?
     - ➔ *Doorvragen naar:*
       - *Video lay-out*
       - *Docent in de video*
       - *Informatie- en presentatiestijl*
       - *Structuur van de video*

4. **Algemene conclusie (max 5 min.)**
   - Welke video sprak je het meest aan en waarom?
   - Wat is voor jou de belangrijkste voorwaarde voor een goede instructievideo voor wiskunde?

Appendix E: Interview Guide for Teacher Focus Groups (Dutch)

Voorbereide vragen focusgroepen docenten

1. **Toelichting doel van onderzoek en audio-opname**

2. **Vragen naar algemeen gebruik (max 5 min.)**
   Deelnemers vragen naar hun gebruik van instructievideo's in het algemeen.
   - Hoe vaak bied je wiskundevideo's aan je leerlingen aan?
   - Met welk doel bied je ze aan?
   - Op welk moment in het onderwijsaanbod bied je ze aan?
   - Op welke manier bied je de video's aan?
   - Waar vind je de video's?
   - Waar let je op bij het selecteren van video's?
   - Heb je een favoriete aanbieder?
   - Maak je zelf wel eens wiskundevideo's? Zo ja, waarom?

3. **Vragen naar mening over verschillende soorten video's (5 ingekorte video's tonen) (max 30 min.)**
   - Wat spreekt je aan bij deze video?
   - Wat vind je minder goed?
   - Wat denk je dat je leerlingen van deze video vinden?
     ➔ *Doorvragen naar:*
       - *Video lay-out*
       - *Docent in de video*
       - *Informatie- en presentatiestijl*
       - *Structuur en elementen van de video*

4. **Algemene conclusie (max 5 min.)**
   - Welke video spreekt je het meest aan? Geldt dit denk je ook voor je leerlingen?
   - Van welke video denk je dat je leerlingen het meest leren?
   - Wat is voor jou de belangrijkste voorwaarde voor een goede instructievideo voor wiskunde?

Appendix F: Note Sheet for Student Focus Groups (Dutch)

Plus- en minpunten voorbeeldvideo's

Video 1 Cijfer: ……

+	-

Video 2 Cijfer: ……

+	-

Video 3 Cijfer: ……

+	-

Video 4 Cijfer: ……

+	-

Video 5 Cijfer: ……

+	-

Appendix G: Online Consent Form Student Focus Groups (Dutch)

Toestemmingsformulier focusgroepen {naam school}

Beste ouder(s)/verzorger(s),

Middels dit digitale toestemmingsformulier wil ik u én uw kind toestemming vragen voor de deelname van uw kind aan de focusgroepen die op {datum} zullen plaatsvinden op {naam school}. Meer informatie over het onderzoek vindt u in het onderstaande informatieblad.

Link naar informatieblad focusgroepen {naam school}

Alvast hartelijk bedankt voor het invullen van het toestemmingsformulier. Voor vragen over het onderzoek kunt u mij bereiken via a.a.kolthof@student.utwente.nl.
Met vriendelijke groet,

Annelies Kolthof
Student Master Educational Science and Technology aan de Universiteit van Twente

Page Break

Ik ben voldoende geïnformeerd over het onderzoek door middel van een separaat informatieblad. Ik heb het informatieblad gelezen en heb daarna de mogelijkheid gehad vragen te kunnen stellen. Deze vragen zijn voldoende beantwoord.

o Ja
o Nee

Mijn kind neemt vrijwillig deel aan dit onderzoek. Het is mij duidelijk dat mijn kind deelname aan het onderzoek op elk moment, zonder opgaaf van reden, kan beëindigen. Mijn kind hoeft een vraag niet te beantwoorden als hij/zij dat niet wil.

o Ja
o Nee

Ik geef toestemming om de gegevens die gedurende het onderzoek bij mijn kind worden verzameld te verwerken zoals is opgenomen in het bijgevoegde informatieblad.

o Ja
o Nee

Ik geef toestemming om tijdens het interview geluidsopnames te maken en de antwoorden van mijn kind uit te werken in een transcript.

o Ja
o Nee

Ik geef toestemming om de antwoorden van mijn kind te gebruiken voor quotes in de onderzoekspublicaties.

o Ja
o Nee

Ik geef toestemming om de bij mijn kind verzamelde onderzoeksdata te bewaren en te gebruiken voor toekomstig onderzoek en voor onderwijsdoeleinden.

o Ja
o Nee

Naam ouder

____

Handtekening ouder

Digitaal handtekeningveld

Naam kind

____

Klas

____

Handtekening kind

Digitaal handtekeningveld

Appendix H: Online Consent Form Teacher Focus Groups (Dutch)

Toestemmingsformulier focusgroepen docenten

Beste docent,

Middels dit digitale toestemmingsformulier wil ik u toestemming vragen voor uw deelname aan de focusgroepen van mijn afstudeeronderzoek. Meer informatie over het onderzoek vindt u in het onderstaande informatieblad.

Informatieblad focusgroepen voor docenten

Alvast hartelijk bedankt voor uw deelname aan het onderzoek. Voor vragen kunt u mij bereiken op a.a.kolthof@student.utwente.nl.

Met vriendelijke groet,

Annelies Kolthof
Student Master Educational Science and Technology aan de Universiteit van Twente

Page Break

Ik ben voldoende geïnformeerd over het onderzoek door middel van een separaat informatieblad. Ik heb het informatieblad gelezen en heb daarna de mogelijkheid gehad vragen te kunnen stellen. Deze vragen zijn voldoende beantwoord.

o Ja
o Nee

Ik neem vrijwillig deel aan dit onderzoek. Het is mij duidelijk dat ik mijn deelname aan het onderzoek op elk moment, zonder opgaaf van reden, kan beëindigen. Ik hoef een vraag niet te beantwoorden als ik dat niet wil.

o Ja
o Nee

Ik geef toestemming om de gegevens die gedurende het onderzoek worden verzameld te verwerken zoals is opgenomen in het bijgevoegde informatieblad.

o Ja
o Nee

Ik geef toestemming om tijdens het interview geluidsopnames te maken en de antwoorden uit te werken in een transcript.

o Ja
o Nee

Ik geef toestemming om de antwoorden te gebruiken voor quotes in de onderzoekspublicaties.

- o Ja
- o Nee

Ik geef toestemming om de verzamelde onderzoeksdata te bewaren en te gebruiken voor toekomstig onderzoek en voor onderwijsdoeleinden.

- o Ja
- o Nee

Naam

____

Handtekening

Digitaal handtekeningveld