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Misconceptions in Physics Explainer Videos and the Illusion of
Understanding: An Experimental Study

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Abstract

Despite their potential, some of the online explainer videos for physics present misconceptions as scientifically correct explanations. Even so, some of these videos achieve good ratings on YouTube. A possible reason is that explainer videos with misconceptions foster an “illusion of understanding”—the mistaken belief that a topic has been understood. In particular, misconceptions close to everyday experiences might appear more attractive than scientifically correct explanations. This experimental study ($N = 149$ physics learners with a low prior knowledge) was conducted to research this effect. Two explainer videos were developed to be comparable in terms of comprehensibility and duration. The explanatory approach was the only difference between the two videos. While the experimental group watched a video introducing the concept of force using misconceptions, the control group watched a scientifically correct video. In the posttest, the experimental group believed that the video including misconceptions was scientifically correct, that they understood the concept, and that they would not require further instruction—indicators of an illusion of understanding. The video was perceived as significantly more understandable than the scientifically correct video ($d = 0.42$). Also, the experimental group learned significantly more *erroneous* knowledge about the misconception than the control group about the *scientifically correct* concept ($\eta^2 = 0.11$). We argue that this might become problematic (a) in physics instruction because students who have watched a misleading video might regard further teaching in school as irrelevant, and (b) learners might tend to rate videos including misconceptions better on an online platform like YouTube.

Keywords: explainer video; misconception; physics; illusion of understanding; YouTube

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Explainer videos—also referred to as, for example, explaining videos, instructional videos, or learning videos—are widely popular on platforms like YouTube. Students watch them, for example, to prepare for exams or simply for entertainment (Wolf & Kratzer, 2015). During the COVID-19 pandemic, the importance of online explanation videos for formal education has likely risen (Voss & Wittwer, 2020). However, such online explainer videos also have the potential to contribute to physics teaching beyond distance learning, for example, to a flipped classroom (van Alten, Phielix, Janssen, & Kester, 2019).

Despite their high potential, the quality of online explainer videos on YouTube greatly varies (Kulgemeyer & Peters, 2016). Frequently, we come across physics videos that we think might even be problematic from a science education perspective. For instance, the German channel “simpleclub” introduces the concept of force with examples such as “If someone is powerful, he has got a lot of force. [...] But also a car has got a lot of force.”¹ We would argue that examples like these might create the impression that force can be stored in a body, which is a well-known misconception among physics learners (Driver, Squires, Rushworth, & Wood-Robinson, 2014). However, as is often the case (Kulgemeyer & Peters, 2016), the comments below the video (e.g., “Thank you. That is much better than what my teacher does.”) and its popularity (nearly 600.000 views as of June 2021, 7441 likes compared to 153 dislikes) do not reflect that the video might be problematic. There are numerous other examples of such physics explainer videos on YouTube.

The good ratings in terms of “views” and “likes” combined with what we think might be a problematic explanatory approach made us wonder about the role of misconceptions in

¹ <https://www.youtube.com/watch?v=xwsAyQGo9dQ> (from 0:43 min on, accessed on 18 June 2021)

MISCONCEPTIONS IN EXPLAINER VIDEOS

physics explainer videos. One possible reason for what we perceive as a gap between actual quality and rating might be that explanations based on misconceptions might sometimes even appear more approachable, in particular, if they arise from everyday experiences (e.g., the misconception that a constant velocity always requires a constant resulting force on an object; Schecker & Wilhelm, 2018). Thus, misconceptions might be “false friends” in explainer videos that create the illusion of a simple explanation that fits everyday experiences and appears seductive and convincing. Learners, however, might be unable to identify these explanatory approaches as oversimplifications. Explainer videos based on misconceptions might, therefore, cause a so-called “illusion of understanding” (Chi, de Leeuw, Chiu, & LaVancher, 1994; Wittwer & Renkl, 2008), the phenomenon that after explanations learners sometimes tend to *think* they have understood a topic when, *in fact*, they have not.

The present article focuses on a potential illusion of understanding after watching an explainer video that included misconceptions. We developed one video including common misconceptions on the concept of force and a second scientifically correct one. Both videos were developed to be comparable in terms of comprehensibility following a framework of effective science explanation videos. In an experiment, we examined how learners with low prior knowledge rated the explanatory quality, whether they realized that the first video is scientifically inaccurate, whether they believed they have understood the topic, and the physics content knowledge they actually learned from the videos.

Theoretical Background

Explainer videos

Explainer videos are short videos (usually between 5 and 10 minutes) aimed to explain a particular topic understandably (Findeisen, Horn, & Seifried, 2019; Kulgemeyer, 2019; Wolf & Kratzer, 2015). In recent research, they have alternatively been referred to as, for example, educational videos (Brame, 2016), instructional videos (Schroeder & Traxler, 2017),

MISCONCEPTIONS IN EXPLAINER VIDEOS

explanatory videos (Findeisen et al., 2019; Kulgemeyer & Peters, 2016), or simply science video (Muller, 2008). Numerous studies have been conducted on the effects and the quality of explainer videos, often based on design principles from the perspective of multimedia learning (Mayer, 2014). For instance, Brame (2016) described guidelines on how to use explainer videos for learning based on cognitive load theory (Sweller, 1988) and active learning. According to Brame's (2016) study, the criteria for explainer videos include, for example, ways to reduce the extraneous cognitive load by eliminating unnecessary information ("weeding").

Schroeder and Traxler (2017) found evidence supporting the idea that reducing distracting features increases the learning outcome of explainer videos. This finding is in consonance with research on instructional explanations that highlights the importance of focusing on the concepts ("minimal explanations"; Anderson, Corbett, Koedinger & Pelletier, 1995; Renkl et al., 2006). "Minimal" in this context refers to explanations that are coherent and free from irrelevant details (Kamalski, Sanders, & Lenz, 2008).

Numerous studies demonstrate the general potential of explainer videos for learning. For example, Lloyd and Robertson (2012) showed that explainer videos enhance the learning of statistics compared to print media. More in detail, research provides evidence of how different features impact the effectiveness of explainer videos. impact their effectiveness. Several studies provide evidence that interactivity, such as making notes, positively influences the learning outcomes (e.g., Delen, Liew & Wilson, 2014; Hasler, Kersten & Sweller, 2007). Hoogerheide, van Wermeskerken, Loyen, and van Gog (2016) observed that compared to peer-explanations, adults as explainers in videos appear more competent, positively influencing the learning outcomes. Fiorella, van Gog, Hoogerheide, and Mayer (2017) suggest that a video should be filmed from the explainer's perspective if complex actions are demonstrated. Plass, Heidig, Hayward, Homer, and Um (2014) showed that an

MISCONCEPTIONS IN EXPLAINER VIDEOS

“emotional design” (shape and colour) positively influences the learning outcomes as well. Also, the structure of an explanation influences its comprehensibility. The results of Seidel, Blomberg, and Renkl (2013), for example, suggest that a structure that introduces the explained principle at first and later illustrates it with examples might be superior in case the learning goal is factual knowledge (“rule-example strategy”). Wittwer and Renkl (2008) conducted a detailed review of relevant literature and concluded that a central factor for successful explanation is an adaptation to a learner’s prior knowledge. Kulgemeyer (2019) highlights that an explainer’s awareness of possible misconceptions is important for a successful adaptation. Tools to achieve successful adaptation have been proposed and empirically validated in the context of research on the model of dialogic explanation in science (Kulgemeyer & Schecker, 2009; Kulgemeyer & Schecker, 2013; Tools for adaptation: Table 1). Adaptation is a major problem for a medium like explainer videos in general (Findeisen et al., 2019; Kulgemeyer, 2019; Kulgemeyer & Peters, 2016). While instructional explanations provided by science teachers can include diagnosis and—based on this—further adaptation, an explainer video cannot be altered once it has been produced. Therefore, integrating interactive elements and integrating the videos into a learning process, for instance, by incorporating learning tasks, is of particular importance. Webb, Ing, Kersting, and Nemer (2006) even suggest that the quality of learning tasks is more important for the learning outcomes than the explanation itself.

In a review of recent research on multimedia learning, Kulgemeyer (2018) developed and empirically tested a framework to improve the effectiveness of science explainer videos based on evidence from studies on instructional explanations (Geelan, 2012; Kulgemeyer, 2019; Wittwer & Renkl, 2008). The framework is in line with other frameworks on the quality of explainer videos like Brame (2016) and Findeisen et al. (2019). It consists of seven factors that have been empirically shown to influence the effectiveness of explainer videos:

MISCONCEPTIONS IN EXPLAINER VIDEOS

(1) the structure of the video (Seidel, Blomberg, & Renkl, 2013), (2) the adaptation to a group of addressees (Wittwer & Renkl, 2008), (3) the use of appropriate tools to achieve adaptation (Kulgemeyer & Schecker, 2013), (4) minimal explanations that keep the cognitive load low (e.g., Anderson et al., 1995), (5) highlighting that the explanation itself is relevant to the learner and what the most relevant parts are (Acuña, García-Rodicio, & Sánchez, 2011), (6) providing learning tasks (Webb, Ing, Kersting, & Nemer, 2006), and (7) a focus on a scientific principle (Renkl et al., 2006). These seven factors can be influenced by using different features (Table 1). Overall, 14 features are highlighted as particularly important to influence the effectiveness of explainer videos. The present study will utilize this framework to develop two videos that possess similar comprehensibility.

Table 1

Framework for effective explanation videos (from Kulgemeyer [2018]).

<i>Factors</i>	<i>Feature</i>	<i>Description</i>
Structure	1.Rule-example, Example-rule	Rule-example structure if the learning goal is factual knowledge. Example-rule structure if the learning goal is a routine or procedural knowledge.
	2.Summarizing	The video summarizes the explanation.
Adaptation	3.Adaptation to prior knowledge, misconceptions, and interest	The video is adapted to a group of addresses and their potential knowledge, misconceptions, or interests. To do so, it uses the “tools for adaptation.”
Tools for adaptation	4.Examples	The video uses examples to illustrate a principle.
	5.Analogies and models	The video uses analogies and models that connect the new information with a familiar area.
	6.Representation forms, demonstrations	The video uses representation forms and/or demonstrations.
	7.Level of language	The video uses a familiar level of language.
	8.Level of mathematization	The video uses a familiar level of mathematization.
Minimal Explanation	9.Avoiding digressions	The video focuses on the core idea, avoids digressions and keeps the cognitive load low.
	10.High coherence	The video connects sentences with connectors, especially “because.”
Highlighting relevancy	11.Highlighting relevancy	The video explicitly highlights why the explained topic is relevant to the explainee.

MISCONCEPTIONS IN EXPLAINER VIDEOS

	12.Direct addressing	The explainees is addressed directly, e.g., by using the second-person singular.
Learning tasks	13. Learning tasks	The video describes learning tasks the explainees can engage in to actively.
Principles	14.New, complex principle	The video focuses on a new science principle that is too complex to understand by self-explanation.

The “illusion of understanding”

An “illusion of understanding” occurs when learners assume to have understood a topic although they actually have not (Wittwer & Renkl, 2008). In this case, learners overestimate the knowledge they have acquired from learning. Research shows that this phenomenon is rather the rule than the exception (e.g., Dunning et al., 2003; Prinz, Wittwer & Golke, 2018). In the context of online explainer videos, there are mainly four factors that can contribute to such an illusion of understanding after watching a video.

First, when confronted with things being explained such as in an online explainer video, learners seem to be particularly prone to overestimate how much they understand. Rozenblit and Keil (2002) call this phenomenon the “illusion of explanatory depth”. Such a phenomenon is likely to occur in understanding natural phenomena such as in physics because people erroneously assume that understanding a phenomenon at one level (e.g., level of observation) automatically leads to understanding this phenomenon at a deeper level (e.g., level of underlying mechanisms).

Second, when watching an online explainer video, learners process visual information in the form of motion pictures. Research demonstrates that such pictures can influence feelings of how much is understood (Salomon, 1984). For example, Lowe (2003) showed that graphical animations can contribute to an illusion of understanding when they attract a learner’s attention to information that is not relevant for learning. Jaeger and Wiley (2014) suggest that the effect of not being able to distinguish “between their feelings of efficacy and their actual level of understanding and effort, [...] could be leading them to make inaccurate

MISCONCEPTIONS IN EXPLAINER VIDEOS

judgments about their comprehension when images are present.” (p. 69). Wiley (2019) calls this a “seduction effect” of pictures.

Third, watching is often the only activity that learners engage in when learning with explainer videos. Without undertaking further learning activities, however, there is no opportunity for learners to become aware of their illusion of understanding. According to Mayer, Fiorella, and Stull (2020), generative activities are an important way to increase the effectiveness of learning from videos. Such generative activities provide learners with cues that they can use to form a more realistic picture of their understanding (e.g., Prinz, Golke, Wittwer, 2019). Research shows that, for example, asking learners to explain newly learned content (e.g., Fernbach et al., 2013) can be useful to confront learners with their limited understanding.

Fourth, in case learners acquire faulty knowledge when learning from an online explainer video, remedial explanations that explicitly highlight a misunderstanding might be helpful (Roelle, Berthold, & Renkl, 2014; Sánchez, García-Rodico, & Acuña, 2009). However, when learners are not aware of which aspects of the remedial explanations address their faulty knowledge, they might perceive such explanations as being irrelevant. In this case, their limited understanding remains unchanged (Acuña et al., 2011).

Kulgemeyer (2018) argues that videos that (unintentionally) contain misconceptions can make learners particularly susceptible to unwarranted feelings of understanding. This is because misconceptions are often based on personal experience and, thus, appear as attractive alternative explanations. In this case, learners might accept misconceptions as explanations of scientific concepts because they might give them the illusion of understanding. Such explainer videos might even result in a more firmly established misconception.

Preconceptions and misconceptions on force

MISCONCEPTIONS IN EXPLAINER VIDEOS

Briefly, a misconception is a “belief that conflicts with currently accepted scientific explanations” (Tippett, 2010, 953). The importance of learners’ ideas about physical concepts or their alternative frameworks is one of the most prominent research topics in science education overall (Duit, 2009). Conceptual change remains one of the most prominent frameworks to understand the learning of science (Duit & Treagust, 2012). It was introduced by Posner, Strike, Hewson, and Gertzog (1982) and has undergone several changes in the following years (Duit & Treagust, 2012). Key ideas are that students already hold conceptions about the physical world before attending the class, their ideas often differ from a scientific view, and they are hard to change (Duit & Treagust, 2012). Moreover, science teaching itself sometimes contributes to developing ideas that deviate from a scientific view (Duit & Treagust, 2012). These ideas have been called—among other things—misconceptions or preconceptions. The terms preconception and misconception are often treated as synonyms (as in the present article), although sometimes preconceptions are understood as ideas about the physical world that learners possess *before* formal science education while misconceptions are ideas that *result* from formal science education (Vosniadou, 2012).

For many concepts in physics, misconceptions stem from everyday language and everyday experiences. For example, following Newton’s second law, “force” is understood as $F=ma$; the force F on an object results in its acceleration a . However, a common misconception on this key concept of classical mechanics is that it takes a force to keep an object at a constant velocity, and if there is no external force acting on that object, it might “store force” to keep moving until this “force” is depleted (Clement, 1982; Schecker & Wilhelm, 2018, p. 73). This misconception accords well with observations of everyday phenomena: a bicycle stops moving once the cyclist stops pedalling. From a physics point of view, the “driving force” on the bicycle (resulting from the interaction of the ground and the bike following Newton’s

MISCONCEPTIONS IN EXPLAINER VIDEOS

third law) is not the only force on the object. The force of friction on the bike needs to be cancelled out by the driving force to keep the bike moving with a constant velocity—in that case, the resulting force on the bicycle, therefore, is Zero.

Another related prominent misconception on the concept of force is that force can be stored in an object (Driver, Squires, Rushworth, & Wood-Robinson, 2014; Schecker & Wilhelm, 2018, p. 73). This is also referred to as an “impetus view” on force (e.g., Eckstein & Shemesh, 1993). This misconception is particularly applicable to German-speaking physics learners, which the present study focuses on. The German word for “force” (Kraft) in everyday language is used nearly interchangeably with the words for “power” and “energy” (Schecker & Wilhelm, 2018). From a physics point of view, a force acts on an object which results in acceleration. However, students often have the misconception that every moving object “has force,” that this force is correlated with its mass and velocity, and that this force is depleted once the object stops being in motion. Of course, there are many more misconceptions on the concept of force documented in the literature (cf. Alonzo & Steedle, 2009). However, the two misconceptions, “force is always needed to keep a body moving” and “force is stored in an object” are very close to everyday observations and very common (Schecker & Wilhelm, 2018). Therefore, we will use these two misconceptions in this study as a basis for the content covered by the videos.

Methods

Research questions

Research question 1: Do misconceptions in an explainer video on the concept of force foster an illusion of understanding?

Misconceptions might foster an illusion of understanding because they are—among other things—often based on personal experience (see above) and, thus, might appear as attractive alternative explanations. For the present study, we conceived of an illusion of understanding

MISCONCEPTIONS IN EXPLAINER VIDEOS

when learners have the mistaken impression that an explanation was (a) was scientifically correct, and (b) comprehensible. Also, they should draw the mistaken conclusions that (c) they have understood the explained concept, and (d) they do not require further instruction on this topic. In a nutshell, we tested for the mistaken belief that an explanation was good and resulted in understanding. We compared the experimental group and the control group for differences regarding the four criteria and tested the following hypothesis:

Hypothesis 1: The illusion of understanding is higher after watching an explainer video that includes misconceptions than after watching a scientifically accurate explainer video.

The second research question focuses on the comparison between the scientifically accurate video and the video including the misconceptions. We wanted to explore the effects that a possible illusion of understanding might have on learners.

Research question 2: Do learners prefer an introductory explainer video with misconceptions to a scientifically correct video?

To measure preference, we first relied on our analysis regarding hypothesis 1 and compared which of the videos the learners evaluate as the more understandable (criterion b).

Second, we compared from which of the videos the learners learn more. We expected that the actual learning progress also impacts the preference of one of the videos. For this part of the study, we did not differentiate between learning the misconception or the correct concept. We expected that after watching the video including the misconceptions, the learners learned the misconception and after watching the scientifically correct video, the learners learned the correct concept. However, since the misconceptions in the videos are closer to everyday experiences and since adaptation to the prior knowledge is the key criterion of explanatory quality, we expected learners to learn more (incorrect knowledge) from the incorrect video than (correct knowledge) from the correct video. The hypothesis for research question 2 is:

MISCONCEPTIONS IN EXPLAINER VIDEOS

Hypothesis 2: Learners learn more incorrect (misconceptual) knowledge from the introductory explainer video including misconceptions than correct (conceptual) knowledge from the scientifically correct video.

Procedure

The study follows an experimental design (Figure 1). Two explainer videos have been developed—one presenting common misconceptions as an alternative explanation and a scientifically correct one. Both videos met standards of explanatory quality by applying the framework of Kulgemeyer (2018), a rating of the explanatory quality, and criteria of text comprehensibility (see section “design of the explainer videos”). We randomly assigned one of the videos to each of the learners. Their experience with online explainer videos and their academic self-concept in physics have been measured. Their prior knowledge on the concept of force was tested in two ways: we tested for the “conceptual knowledge” and the “misconceptual knowledge” (cf. instruments section). The first evaluates how well the learners handle the scientifically correct knowledge, the second how “well” they solve items based on the misconception (or how much they are convinced by the misconception).

Following the pretest, the experimental group watched the video with the misconceptions and the control group watched the video with the scientifically correct explanation.

The posttest measured the four aspects of an illusion of understanding (see section “research questions”). Additionally, it included scales for the conceptual and the misconceptual knowledge (the same test as in the pretest).

To fulfil ethical standards, the experimental group received further instruction after the experimental study. We revealed that the video they watched contained incorrect information while presenting an attractive misconception as the correct explanation. Not only did this group receive the correct explanation afterwards, but they also participated in a group discussion on the topic that these kinds of explanations can be found on YouTube in

MISCONCEPTIONS IN EXPLAINER VIDEOS

explainer videos with millions of views. The key message was: be critical with explainer videos from unknown sources.

Figure 1

Experimental design and procedure of the study

Participants

The sample comprised of German-speaking students from an introductory physics course that is mandatory for first-semester pre-service elementary teachers. Usually, these learners have very little knowledge of physics as it is an optional subject in the last three years of school.

The entire group of $N = 149$ learners (126 female, 23 male, 0 diverse; $n_E = 69$ in the experimental group and $n_C = 80$ in the control group) participated in the study. As expected, their experience was low; 114 of the learners had not enrolled in a physics course in the last three years of school (the academic preparation phase that leads to the German “Abitur” [equivalent to A levels]), 26 of them had taken a basic physics course, and eight took physics as a major course for the German Abitur.

Design of the explainer videos

The explanatory approach (misconception versus scientifically correct) was the only difference between the two videos. The video offering an explanation based on the misconception explained the concept of force relying on the two misconceptions “force is always needed to keep a body moving” and “force is stored in an object.” The other video

MISCONCEPTIONS IN EXPLAINER VIDEOS

explained the concept of force correctly as the reason for an acceleration ($F=ma$) and that it does not require a force to keep an object moving (Newton's first law).

Both videos were of comparable quality to allow the comparison of the explanatory approaches. Based on the criteria of Kulgemeyer (2018), both videos followed a rule-example structure and included a summary in the end. Both videos used the same example and representation forms, level of mathematization, and level of language. Both videos focused on the concept (minimal explanation), avoided digressions, and had high coherence by connecting the sentences with connectors. Both videos used prompts to highlight relevant parts and addressed the explainee directly. Both videos ended with the same learning task, even though the learners had just enough time to think about the learning task (about 5 min for each group). Finally, both videos explained the same complex principle, however, using different approaches. Regarding the 14 criteria of Kulgemeyer (2018), therefore, no difference between the videos was observed. Also, we administered the questionnaire for the perception of the video comprehensibility (cf. section "instruments") to a group of 27 pre-service physics teachers at the end of their Bachelor's programme in physics in order to provide an empirical argument that both videos are comparable in terms of comprehensibility. Out of them, 13 of them watched the scientifically correct video, 14 watched the videos including misconceptions. Both groups were asked to rate the comprehensibility, not the scientific correctness. We could not find a difference between the groups ($t(25) = -0.92, p = 0.93$).

Table 2 provides a brief overview of the scripts of the videos. They have been translated since the explainer videos were produced in the German language. To ensure that both videos were comparable in terms of complexity of language, we calculated the readability scores of the texts. We used the readability coefficient LIX for this purpose because it works well with

MISCONCEPTIONS IN EXPLAINER VIDEOS

the German language (Lenhard & Lenhard, 2014). Both scripts were found to be comparable with scores indicating a low complexity ($LIX_{\text{scientifically correct}} = 35.60$; $LIX_{\text{misconceptions}} = 33.20$).

Table 2

Comparison of the explainer videos (parts of the scripts, translated from German language)

<i>Video with correct scientific explanation</i>	<i>Video including misconceptions</i>
<i>[Pointing out that force is an important concept in physics, giving overview of the video.]</i>	<i>[Identical introduction: see left column]</i>
<p><i>In a nutshell, force is the reason why an object accelerates. A force always acts with a certain “strength” in a particular direction. This means that an object will not accelerate if no force acts on it.</i></p> <p><i>Of course, in that case, the object may rest, but it may also move with a constant velocity. In both cases, the object would not accelerate and, therefore, in both cases no force acts on the object. How strong the acceleration is, given that a certain force is acting on an object depends on the mass of the object. If it has a lower mass, the acceleration will be higher. If it has a higher mass, the acceleration will be lower.</i></p> <p><i>This idea on force can be used to describe all kinds of moving objects.</i></p> <p><i>[Applying this idea on the example of a golf ball that stops moving after it gets hit because of the force of friction.]</i></p> <p><i>Let us sum up:</i></p> <ul style="list-style-type: none"> <i>• A force causes an acceleration of an object in a certain direction.</i> <i>• It does not matter if the object rests or moves—if not force acts on it, it does not accelerate.</i> <p><i>[Ending the video with a learning task: use the explained ideas to explain why a bicycle accelerates if you go downhill.]</i></p>	<p><i>In a nutshell, force is a physics concept used to explain why an object moves. Of course, it depends on how heavy the object is and how fast it moves. Generally speaking: an object always has a high force if it is fast and heavy. If you compare two objects with the same velocity, the one with the higher mass also has the higher force.</i></p> <p><i>If an object has no more force, it cannot move and rests. If you see an object resting, you know that it has no force stored.</i></p> <p><i>This idea on force can be used to describe all kinds of moving objects.</i></p> <p><i>[Applying this idea on the example of a golf ball that stops moving after it gets hit once the stored force is depleted.]</i></p> <p><i>Let us sum up:</i></p> <ul style="list-style-type: none"> <i>• A body always has a high force if it is fast and heavy.</i> <i>• Without force, an object will not move at all.</i> <p><i>[Identical learning task (see left column)]</i></p>

Instruments

Control variables

To control for background variables, we administered a questionnaire consisting of questions about gender, final school grade (“Abiturnote”), experience with explainer videos (5-point

MISCONCEPTIONS IN EXPLAINER VIDEOS

Likert scale, e.g., “I have often watched explainer videos on topics from school or university”), and academic self-concept in physics (5-point Likert scale, six items, $\alpha = 0.90$, e.g., “I get good grades in physics”).

Illusion of understanding

To characterize the learners’ illusion of understanding, we applied four criteria. Individuals should have the mistaken impression that the explanation was (a) was scientifically correct, and (b) comprehensible. Also, they should draw the mistaken conclusions that (c) they have understood a concept, and (d) they do not require further instruction on this topic. The criteria (a) and (b) concern the explanation itself, (c) and (d) concern the conclusions the individuals draw from the explanation about their understanding.

For a content valid assessment, all four criteria need to be contained in the scale for the illusion of understanding. Among other things, we addressed the criteria by asking for agreement with statements on a Likert scale (1 indicates a total agreement, 5 a total disagreement; sample items: criterion (a) the video was scientifically correct, (c) I understand what force means in physics, (d): I do not need to learn more on the concept of force to fully understand it).

For criterion (b), we measured the perception of video comprehensibility as a subscale. It was measured on a global level by asking for the degree of agreement with the statement “the video was easy to understand” (1 indicates a total agreement, 5 a total disagreement) and more in detail by we asking for the perception of the aspects that influence the comprehensibility of an explainer video based on the framework of Kulgemeyer (2018) (e.g., “the examples used in the video were well-chosen”). This sub-scale was found to be reliable ($\alpha = 0.72$, 6 items).

The final scale consisting of items for all four criteria was found to be reliable as well ($\alpha = 0.75$, 10 items).

MISCONCEPTIONS IN EXPLAINER VIDEOS

Conceptual and misconceptual knowledge

We tested for conceptual knowledge (scientifically correct knowledge) and misconceptual knowledge (knowledge that would be correct if the misconception was correct—or, in other words, the degree of how much a student holds a misconception). The test consists of nine items, each of which including a situation or a statement that can be explained by either a misconception or a scientifically correct concept.

All items were multiple-choice with one (or more) of the options being the scientifically correct solution and one (or more) of the options being a solution one would pick when holding a misconception on force. Many test inventories (such as the Force Concept Inventory [Hestenes, Wells & Swackhammer, 1992] which we used as a role-model) work similarly using options that would be used when holding a misconception as distractors for multiple-choice items. However, while the misconceptual knowledge would usually simply be counted as incorrect in studies on physics misconceptions, it is a construct with actual learning opportunities for the experimental group in our study. Figure 2 shows a sample item. In the case of the item in figure 2, the correct solution based on the scientifically correct concept would be b) and c), while someone holding the misconception that force can be stored should answer a) and d). The scales were calculated by summing up all scientifically correct answers by an individual (scale for conceptual knowledge) and all answers by an individual indicating a misconception (scale for misconceptual knowledge). Overall, both scales were found to be reliable (conceptual knowledge: $\alpha = 0.71$; misconceptual knowledge: $\alpha = 0.85$). Since it is likely that watching explainer videos without further instruction only helps to develop declarative knowledge on force (as shown by Kulgemeyer [2018]), it was necessary to keep the items as close as possible to the learning opportunities of both videos. We, therefore, ensured that learning opportunities for all items occur in both videos by comparing the items and the scripts.

MISCONCEPTIONS IN EXPLAINER VIDEOS

Figure 2

Sample item for conceptual knowledge and misconceptual knowledge (translated from the German language)

- Which statement / statements on the physical quantity “force” do you agree with?
- a) A body can store a force
 - b) A force can act on a body
 - c) Forces always act on two or more bodies
 - d) One body may transfer its force to another body – in that case, the first body loses its force while the second body gains it

Results

None of the variables examined in this study violated the assumptions of a normal distribution and equality of variances. To analyze the data, we used *t*-tests and one-way ANOVAs. Table 3 shows the descriptive statistics of the study variables.

Table 3

Descriptive Statistics of Study Variables

		Experimental Group	Control Group	
		<i>M (SD)</i>	<i>M(SD)</i>	Range
<i>Knowledge</i>				
	Conceptual Knowledge (Pre)	0.48 (0.20)	0.45 (0.19)	0-1
	Misconceptual Knowledge (Pre)	0.34 (0.16)	0.33 (0.16)	0-1
	Conceptual Knowledge (Post)	0.50 (0.19)	0.63 (0.18)	0-1
	Misconceptual Knowledge (Post)	0.65 (0.17)	0.35 (0.17)	0.1
<i>Illusion of Understanding</i>				
	Scale	1.66 (0.45)	1.71 (0.42)	1-5
	Subscale: Perception of Video Comprehensibility	1.55 (0.47)	1.61 (0.47)	1-5
<i>Control Variables</i>				
	Gender	0.88 (0.32)	0.83 (0.39)	0-2
	Final school grade	2.14 (0.69)	2.34 (0.59)	1-6
	Academic self-concept physics	3.19 (0.74)	3.31 (0.76)	1-5
	Experience with explainer videos	1.96 (1.06)	1.83 (0.99)	1-5

Note. *M* = means, *SD* = standard deviation. Range Gender: 0 = male, 1 = female, 2 = diverse

Control variables

MISCONCEPTIONS IN EXPLAINER VIDEOS

Regarding the pretest scores, there was no noticeable difference between the control group and the experimental group for either their misconceptual knowledge ($F(1,147) = 0.40, p = 0.53$) or their scientifically correct conceptual knowledge ($F(1,147) = 1.06, p = 0.31$). The groups did not differ in gender ($\chi^2(1) = 1.03, p = 0.31$), their final school grade ($t(92) = 1.48, p = 0.14$), their academic self-concept in physics ($t(147) = 1.00, p = 0.32$), and their experience with explainer videos ($t(147) = -0.78, p = 0.44$).

Research question 1: Do misconceptions foster an illusion of understanding?

Hypothesis 1: Illusion of understanding higher after video with misconceptions

The t -test regarding the scale for an illusion of understanding reveals a significant agreement for both groups with the believe that the explanation was good and resulted in an individual's understanding (experimental group: $M = 1.66, SD = 0.45, t(68) = -24.86, p = 0.00$; control group: $M = 1.71, SD = 0.42, t(79) = -27.74, p = 0.00$). On a scale from 1 to 5 (where 1 indicates a total agreement and 5 a total disagreement) both scores differ significantly from the neutral score of 3 and represent a significant agreement.

The subscale for video comprehensibility differs significantly from the neutral score of 3 as well (experimental group: $M = 1.55, SD = 0.48, t(68) = -25.76, p = 0.00$; control group: $M = 1.61, SD = 0.47, t(79) = -26.71, p = 0.00$). We want to highlight the four items that address the four criteria for an illusion of understanding directly. Regarding the perceived scientific correctness (criterion a), both groups agree significantly (experimental group: $M = 1.52, SD = 0.78, t(68) = -15.77, p = 0.00$; control group: $M = 1.36, SD = 0.64, t(79) = -22.84, p = 0.00$). Also, regarding criterion (b), learners from both groups agree significantly with the statement "The video was easy to understand" (experimental group: $M = 1.43, SD = 0.56, t(68) = -15.77, p = 0.00$; control group: $M = 1.73, SD = 0.78, t(79) = -14.64, p = 0.00$). Regarding criterion (c) ("I understand what force means in physics"), both groups agree significantly as well (experimental group: $M = 2.03, SD = 0.64, t(68) = -12.59, p = 0.00$; control group: $M =$

MISCONCEPTIONS IN EXPLAINER VIDEOS

2.09, $SD = 0.68$, $t(79) = -12.02$, $p = 0.00$). Also, regarding criterion (d) (“I do not need to learn more on the concept of force to fully understand it”), both groups agree significantly (experimental group: $M = 2.30$, $SD = 0.94$), $t(68) = -6.12$, $p = 0.00$); control group: $M = 2.19$, $SD = 1.07$, $t(79) = -6.80$, $p = 0.00$).

Regarding the complete scale ($t(147) = 0.65$, $p = 0.51$), the subscale for video comprehensibility ($t(147) = 0.78$, $p = 0.44$), and three of the four items addressing the four criteria for an illusion of understanding directly we cannot identify a significant difference between both groups using t-tests. However, regarding criterion (b), the t-test revealed a significant difference between the groups ($t(147) = 2.58$, $p = 0.01$, $d = 0.42$). On a global level, therefore, the comprehensibility of the video including the misconceptions was better evaluated.

Research question 2: Do learners prefer an introductory explainer video including misconceptions over a scientifically correct video?

Hypothesis 2: Higher learning gain after video with misconceptions

To test this hypothesis, we compared the pre- and the posttest scores for the scales for conceptual and misconceptual knowledge (Figure 3). After the intervention, the experimental group outperformed the control group regarding the scientifically wrong, misconceptual knowledge ($F(1,147) = 127.99$, $p < 0.001$, $\eta^2 = 0.47$) with a large effect. The control group outperformed the experimental group regarding the scientifically correct knowledge ($F(1,147) = 19.68$, $p < 0.001$, $\eta^2 = 0.12$) with a medium effect.

Figure 3

Comparison of the experimental group and the control group regarding their misconceptual knowledge (MC) and their scientifically correct knowledge (correct). Given are test scores (from 0 to 1, pre and post) and the standard error of the mean.

MISCONCEPTIONS IN EXPLAINER VIDEOS

The difference between the pretest score and the posttest score for the experimental group regarding the scientifically correct knowledge was not significant ($F(1,1536) = 0.19, p = 0.67$), while the experimental group achieved significantly more misconceptual knowledge ($F(1,136) = 124.56, p < 0.001, \eta^2 = 0.48$). The control group achieved significantly more correct knowledge ($F(1,158) = 39.43, p < 0.001, \eta^2 = 0.20$), their misconceptual knowledge did not change significantly ($F(1,158) = 0.58, p = 0.45$).

We compared the learning gains between the experimental group (regarding their wrong misconceptual knowledge) and the control group (regarding their scientifically correct knowledge) by calculating a scale for the learning gains. This scale included the learning gains (between 0 and 1) for the respective learning opportunity of the groups. The experimental group learned significantly more about the misconceptual knowledge (Learning gain: $M = 0.31, SD = 0.20$) than the control group about the scientifically correct knowledge (Learning gain: $M = 0.18, SD = 0.17$) with a medium effect size ($F(1,147) = 18.39, p < 0.001, \eta^2 = 0.11$).

Discussion

The findings are not fully in line with hypothesis 1. After watching the video including misconceptions, learners think that (a) the video was scientifically correct, (b) the video was

MISCONCEPTIONS IN EXPLAINER VIDEOS

comprehensible, (c) they have understood the concept, and (d) they do not require further instruction on this topic.

However, it makes no difference whether the learners watched the scientifically correct video or the video including the misconceptions—both groups fulfil the criteria for an illusion of understanding. That result is in line with prior research indicating video and animation have “seductive effects” that foster an illusion of understanding (see section “illusion of understanding”). It suggests that the seductive effects of video, in general, are larger than the effects of the presence of misconceptions; however, that can only be examined in future studies.

Therefore, the illusion of understanding is probably not *caused* by the occurrence of misconceptions in the videos. Nevertheless, we regard this belief of understanding in both groups as a problem. The perceived relevancy of an explanation affects its effectiveness (Acuña, García-Rodico & Sánchez, 2011; Kulgemeyer, 2019). If learners watched a video including misconceptions on the force concept and afterwards believed they understood the topic and do not require further instruction, they would likely perceive further explanatory attempts by their teachers as redundant and irrelevant. This would mean that it might be hard for these teachers to cognitively activate their students—a major prerequisite for successful instruction (Dorfner, Förtsch & Neuhaus, 2017). This should be examined more in detail in future studies.

Interestingly, on a global level, the video including misconceptions was rated as the more understandable video. This makes sense since the misconceptions in the video are likely to be present in the group and close to their prior knowledge because they result from everyday thinking on the concept of force and its meaning in everyday language (Schecker & Wilhelm, 2018). Adaptation to the prior knowledge is a key aspect of successful explanations (Wittwer & Renkl, 2008) and the video including the misconceptions might have been better adapted

MISCONCEPTIONS IN EXPLAINER VIDEOS

to the erroneous prior knowledge. However, more in detail, the perception of the different aspects of effective explainer videos following Kulgemeyer (2019) for the video including misconceptions was *not* better.

However, the results are in line with hypothesis 2. Both groups achieved significant learning gains matching their respective learning opportunities. We regard this match between learning gains and learning opportunities as an argument for the validity of the research because the test instruments were developed to reflect the learning opportunities. However, regarding the learning gains, the experimental group outperformed the control group significantly and with a medium effect. The learners learn more *erroneous knowledge* from the video including the misconceptions than the control group learned *correct knowledge* from the scientifically correct video. Again, the reason might be that a video including misconceptions is closer to the prior knowledge and, therefore, better adapted to the explainees' needs.

Overall, the learners, therefore, evaluate the video including the misconceptions globally as the more understandable video and they learn more from it than from the scientifically correct one— even though what they learned from it is wrong. Additionally, they tend to think that they understood the topic after watching both videos, that both videos contain good explanations, and they regard both videos as scientifically correct.

Of course, our study also has limitations. The topic was limited to misconceptions on force and misconceptions close to everyday experiences. For misconceptions on other physics concepts that do not play such a prominent role in everyday life, the results might not be so clear. Also, it is unclear whether or not the perception of explainer videos as being scientifically correct has been influenced by the study context. The learners have been informed that the material is authentic for online explainer videos, but maybe their perception that the videos are scientifically correct is influenced by the use of the videos in a study. To

MISCONCEPTIONS IN EXPLAINER VIDEOS

gain first insights into the question of if high prior knowledge helps to avoid an illusion of understanding we conducted a post-hoc analysis. For this purpose, we added additional $N = 14$ more learners with higher prior knowledge (from a course for pre-service physics teachers in the first semester) into the experimental group to increase the variance of prior knowledge. For then overall $N = 83$ learners we found significant and meaningful correlations between the physics prior knowledge (conceptual knowledge) and *disagreement* (a) with the belief that the video is scientifically correct ($r = 0.402, p < 0.01$) and (b) the belief that no further physics instruction is required ($r = 0.283, p < 0.05$). We would argue that these results are first hints that prior knowledge helps to critically evaluate explainer videos and overcome an illusion of understanding, but further studies are needed.

We believe that these results have implications for classroom practice. Based on the results, we developed the hypothesis is that learners might rate the video including misconceptions good on a platform like YouTube – and possibly even better than the scientifically correct one. This might result in enhancing the visibility of videos with misconceptions as they may get more prominently featured on searching for videos about a particular concept. Kulgemeyer and Peters (2016) already demonstrated that neither likes nor views reflect explaining quality, and the described hypothesis might contribute to explain this.

We still believe that explainer videos on platforms like YouTube have great potential and can play a vital role in science education research. We consider it important for future science teacher education to include explainer videos and how to implement them into learning processes as a central topic. We think that this does not only comprise the strengths of the medium but also possible problems. Videos from the internet including misconceptions will never disappear and science teachers should be aware of their existence. It might even be a good idea to include instruction on how to deal with such video into physics teaching.

MISCONCEPTIONS IN EXPLAINER VIDEOS

Providing examples for videos including misconceptions might contribute to convincing students that content on YouTube should be critically evaluated.

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MISCONCEPTIONS IN EXPLAINER VIDEOS

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