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Generating an instructional video as homework activity is both effective and enjoyable

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ABSTRACT

Research with adolescent and university students has shown that after studying a text, teaching its content to a fictitious peer on camera fosters learning compared to restudying. We investigated the effects of generating a teaching video during homework in a sample of primary school students ($N = 131$) in comparison to restudying and summarizing. Students were provided with a text and a homework assignment over the weekend. The Restudy Condition was instructed to study the text as often as necessary. The Summarizing and Video Condition were instructed to study the text as often as necessary and to then generate a summary or teaching video about the text, respectively. Teaching on video was perceived as more enjoyable than restudying or summarizing, and improved test performance compared to restudying. Teaching on video was not more effective than summarizing; however, summarizing did not improve test performance compared to restudying, as teaching did.

1. Introduction

Learning from instructional video is immensely popular and a key ingredient of many contemporary instructional approaches, such as massive open online courses and flipped classrooms (De Koning, Hoogerheide, & Boucheix, 2018; Fiorella & Mayer, 2018; Kay, 2012). Research has predominantly focused on instructional videos as a strategy for delivering information to learners (e.g., Fiorella, Van Gog, Hoogerheide, & Mayer, 2017; Kant, Scheiter, & Oschatz, 2017). However, there is a growing interest in the effects of instructing students to generate their own instructional videos as a learning activity (e.g., Gold et al., 2015; Orús et al., 2016).

Recent laboratory research on learning-by-teaching has shown that generating an instructional video can be an effective strategy for learning. For instance, Fiorella and Mayer (2013, 2014) conducted multiple experiments in which university students learned about the Doppler Effect. Students studied an expository text with the expectancy of having to complete a test about the material (test expectancy condition), with the expectancy of having to teach the material (teaching expectancy condition), or with the expectancy of having to teach followed by actually teaching the content for 5 min to a (fictitious) fellow student on camera (teaching on video condition). Fiorella and Mayer found inconsistent effects of studying with a teaching expectancy compared to studying with a test expectancy. However, those in the teaching on video condition consistently outperformed those in the test expectancy and teaching expectancy conditions on an immediate and a delayed test comprised of comprehension questions (medium to large effect). Similar results were obtained by Hoogerheide, Loyens, and Van Gog (2014a) with a sample of secondary education students (Experiment 1) and university students (Experiment 2) and different materials (i.e., a text about syllogistic reasoning and retention and transfer tasks). Again, only teaching on video consistently improved learning outcomes compared to studying for a test with a medium to large effect (an effect that has since then been replicated in other studies: e.g., Hoogerheide, Deijkers, Loyens, Heijltjes, & Van Gog, 2016; Koh, Lee, & Lim, 2018).

Teaching on video research also frequently examined effects on self-reported (i.e., subjective) mental effort invested in learning or the posttest. Findings consistently showed that generating a teaching video was perceived as more effortful than studying for a test (e.g., Hoogerheide, Deijkers et al., 2016). When combined with the finding that teaching on video improved learning, it seems that this additional (perceived) effort investment can be qualified as working memory resources allocated to processes relevant for learning (i.e., germane cognitive load; Sweller, 2010). Moreover, there seemed to be no significant

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difference between teaching on video and studying for a test in perceived effort invested on the test problems (e.g., Hoogerheide et al., 2014a). This result has been argued to indicate an efficiency benefit in favor of the teaching condition, as performing better on a posttest with equal or less reported effort investment provides an indication of higher quality cognitive schemata (for a more elaborate discussion of efficiency, Van Gog & Paas, 2008). It is as yet unclear, however, which working mechanism is responsible for the teaching on video effect and whether teaching on video is an effective strategy in applied settings and for primary school students. Several potential mechanisms for the teaching on video effect have been proposed.

1.1. Which mechanism drives the teaching on video effect?

As initial studies did not control time on task (e.g., Fiorella & Mayer, 2013), it was possible that the benefits of teaching on video resulted simply from spending more time on the teaching activity. However, this does not seem to be the case, because the benefits were also found when time on task was controlled (e.g., Fiorella & Mayer, 2014, Experiment 2; Hoogerheide, Deijkers et al., 2016, Experiment 2).

Another potential explanation would be that it is not so much the activity of teaching, as the retrieval of information from memory that it inherently entails, and which has been shown to improve learning (Fiorella & Mayer, 2016; Rowland, 2014). Yet teaching on video was also found to result in better learning outcomes than restudy when those who restudied were provided with a cued-recall retrieval practice activity (Hoogerheide et al., 2014a, Experiment 2; Hoogerheide, Deijkers et al., 2016, Experiment 2) or had access to the learning material during teaching (Hoogerheide, Renkl, Fiorella, Paas, & Van Gog, 2018). This suggests there is something else involved in the teaching activity that causes the benefits for learning, and there are two (not mutually exclusive) main explanations of what that might be.

First, the *generative learning hypothesis* builds on generative learning theory and postulates that teaching improves learning because explaining (for oneself or for others) stimulates learners to engage in generative processes that are effective for (deep) learning, such as selecting the most relevant information of the material, organizing the material into a coherent narrative, elaborating on the material, repairing knowledge gaps, and integrating the newly acquired knowledge with existing prior knowledge (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013; Fiorella & Mayer, 2016; Kobayashi, 2018; Richey & Nokes-Malach, 2015; Roscoe & Chi, 2007, 2008; Wylie & Chi, 2014).

Second, the *social presence hypothesis* argues that an awareness of the potential audience during teaching (i.e., feelings of social presence; Gunawardena, 1995) elicits (meta)cognitive and motivational processes that improve learning (Hoogerheide, Deijkers et al., 2016). On a (meta) cognitive level, an awareness of the potential audience and the belief that the explanations can affect others (i.e., productive agency; Okita & Schwartz, 2013; see also research on accountability; Tetlock, 1985) could be a motivating factor, stimulating learners to engage in effective study processes, such as considering whether the imagined recipient would comprehend their explanations and trying to generate an accurate and complete message (Ploetzner, Dillenbourg, Preier, & Traum, 1999). On a physiological level, feelings of social presence could elicit higher levels of arousal, which refers to a state of feeling excited or activated. Research has shown that merely believing that someone else is watching you (i.e., a fictitious audience) can evoke arousal (e.g., Somerville et al., 2013). Based on related research, one could indeed expect a fictitious audience to improve learning via arousal: Arousal is known to enhance various determinants of learning such as working memory capacity and memory consolidation (Arnsten, 2009; Roozendaal, 2002; Sauro, Jorgensen, & Pedlow, 2003) and to mediate the effect that a real (physically-present) audience has on task performance (Aiello & Douthitt, 2001; Bond & Titus, 1983).

Because the effectiveness of generating a teaching video has predominantly been compared to restudying, which lacks both the generative learning and social presence components inherent to teaching on video (e.g., Fiorella & Mayer, 2014, Experiment 2; Hoogerheide et al., 2014a, Hoogerheide, Deijkers et al., 2016, Experiment 2), it is unclear whether the benefits of teaching on video are a result of engaging in generative processing or social presence. One exception comes from the study by Hoogerheide, Deijkers, and colleagues (2016), who had students either restudy, teach the study material to a fictitious peer in writing, or teach the material on video. They found evidence for the social presence hypothesis: Providing explanations to a fictitious peer student in writing (generative processing, but lower in social presence) was not more beneficial for learning than restudy, yet teaching on video (higher in social presence) was. Moreover, the video explanations contained proportionally more self-other referential words than the written explanations, which suggests that students also experienced more feelings of social presence. A related study on learning-by-teaching by Rittle-Johnson, Saylor, and Swygert (2008) also points towards the social presence hypothesis, as they found that generating explanations for a family member (generative processing, high in social presence) enhanced performance on a problem-solving transfer test compared to generating explanations for oneself (generative processing, no social presence) or retrieval practice (generative processing, no social presence). Lastly, Hoogerheide et al. (2018) recently found that teaching on video was associated with more arousal than studying, although there was no significant association between students' arousal and posttest performance.

1.2. Is teaching on video an effective strategy in applied settings?

Because thus far the available research has only been conducted in highly controlled environments (e.g., Fiorella & Mayer, 2013, 2014; Hoogerheide et al., 2018, 2014a; Lachner, Ly, & Nückles, 2018), an important open question is whether teaching on video would also be an effective learning strategy in applied settings, where an experimenter is not present and there is no strict control of time on task (cf. Hoogerheide, Deijkers et al., 2016).

Several studies did investigate whether generating an instructional video would enhance learning in a classroom context, but these studies often had some methodological limitations. That is, they often did not include a control condition, so any benefit of creating an instructional video could simply be a result of time on task, or they failed to isolate the activity of creating an instructional video from other learning activities, making it difficult to determine whether any effects could be attributed to the act of creating the video. Moreover, these studies relied heavily on subjective perceptions of learning, which do not necessarily correspond with objective measures because people are often unable to accurately estimate their own learning or performance (e.g., Kruger & Dunning, 1999).

For example, Spires, Hervey, Morris, and Stelpflug (2012) instructed secondary education students to create an instructional video in collaboration with other students. The authors concluded that the process of generating the instructional video enhanced students' learning and motivation. Because of the reliance on self-report data, the collaborative setting, and the lack of a control condition, however, it is unclear whether video creation would be more effective and enjoyable compared to other activities, and what role collaboration played. Another example is the study of Stanley and Zhang (2018). They randomly allocated university students enrolled in an economics class to follow a course without (control condition) or with an additional video creation activity (video condition). The authors reported a small positive effect of creating an instructional video on learning, engagement, and learning enjoyment. However, it is unclear whether the effects could be solely ascribed to the instructional video creation activity, because both groups engaged in many other learning activities throughout the course and only the video condition watched and rated other students' videos.

The suggestion that generating an instructional video might be a very enjoyable and engaging way of learning in applied settings (e.g., Stanley & Zhang, 2018) is interesting. Despite the fact that the social presence hypothesis predicts that an awareness of the potential audience during teaching in part improves learning via motivational processes (Hoogerheide, Deijkers et al., 2016), it is still an open question whether teaching on video would be more motivating than other instructional activities. Learning enjoyment is an important component of intrinsic motivation (Deci & Ryan, 1985) and is important to take into account because it can be an important indicator of whether or not students would use a learning strategy in beyond the experimental context (Yi & Hwang, 2003). Moreover, outside of experimental settings, enjoyable learning activities may stimulate engagement factors such as persistence and thereby improve learning outcomes (Dweck, 1986).

1.3. Is teaching on video an effective strategy for primary school students?

Another open questions that is relevant for educational practice is whether teaching on video would also be an effective strategy for primary school students. Although generating instructional videos seems to be increasingly used with younger students (e.g., Gold et al., 2015; Lenhart, 2012), thus far, teaching on video research has only been conducted with adolescents and young adults (e.g., Fiorella & Mayer, 2014; Hoogerheide et al., 2014a; Lachner et al., 2018). It is possible that primary school students would not benefit as much from generating a teaching video as adolescents and adults do, because they have fewer cognitive resources available (e.g., lower working memory capacity, processing speed, fluid intelligence, and attention; Cowan et al., 2005; Johnson, Im-Bolter, & Pascual-Leone, 2003) to deal with both the heavy task demands of engaging in cognitive processing and the pressure of the imagined audience. Nevertheless, research by Muis, Psaradellis, Chevrier, Leon, and Lajoie (2016) did suggest that studying materials with a teaching expectancy can help primary school students to achieve better learning outcomes than studying for a test in a classroom setting, so it is possible that teaching on video might also foster primary students' learning.

1.4. The present study

The present study investigated whether teaching on video during homework would improve primary school students' learning (as measured by performance on a conceptual knowledge test) compared to restudying or summarizing. A homework assignment was used so that students could generate and record their explanations at a time and place of their own preference and without being seen by their classmates. Summarizing was used as a control condition because it is a commonly used learning activity that also promotes generative processing (Doctorow, Wittrock, & Marks, 1978; Fiorella & Mayer, 2016; King, 1992; Wittrock & Alesandrini, 1990) but lacks the social presence component (i.e., the imagined/fictitious audience) that is inherent in teaching or explaining activities. Effects on self-reported mental effort invested in the learning and test phase were also examined to shed light on the efficiency of the instructional conditions (see Van Gog & Paas, 2008). We also examined effects on self-reported enjoyment as an important aspect of intrinsic motivation (Deci & Ryan, 1985) and an indicator of the actual use of an learning strategy outside of the experimental context (Yi & Hwang, 2003).

It was hypothesized that both generative learning homework activities (i.e., summarizing and video creation) would be perceived as more effortful and lead to better learning outcomes than restudying. Summarizing, like explaining, helps learners to select the key information in the text, to organize the material into a coherent narrative, and to integrate newly acquired knowledge with existing prior knowledge (Dunlosky et al., 2013). While restudy provides an additional opportunity for learning that students could use to focus on and generate self-explanations about the part of the material that they have not yet mastered, research suggests that restudy is a rather poor strategy for acquiring conceptual knowledge (Dunlosky et al., 2013). Video creation was expected to be most effective for learning (i.e., learning outcomes: video > summary > restudy), because of the social presence component that is inherent in teaching activities (cf. Hoogerheide, Deijkers et al., 2016). An awareness of the potential audience during teaching could improve learning through an increase in arousal as well as by motivating students to engage in additional effective generative processes.

Video creation was also expected to be most enjoyable. Although it is unclear how creating an instructional video compares to other activities, findings suggest that video creation is an enjoyable activity (e.g., Stanley & Zhang, 2018) likely in part because a video is a creative product that can be shared with others (Spires et al., 2012). Moreover, younger students tend to use this strategy in their free time (e.g., Lenhart, 2012), which does not apply (to the same extent) to restudy or summarizing. Whether summarizing would be more or less enjoyable than restudy is an open question.

2. Method

2.1. Participants and design

A multi-level simulation study showed that to be able to detect the medium to large effect of teaching on video found in the literature, at least 120 participants would be needed (please see Appendix A for more information on the power analysis). The parents or caretakers of students enrolled in the 8th grade of 9 different Dutch primary schools (cf. USA grade 6, ages 11–13) were asked to provide their written (active) consent that would allow their child to participate in our study. Students with parental consent were asked to give consent themselves as well. Of the 158 participants who had received parental consent and provided consent themselves, 27 were removed from the sample, either for being non-native speakers ($n = 3$), for being absent during one or both of the sessions of the study ($n = 9$), or for indicating after the study that they had failed to comply with the instructions ($n = 15$[1]). The final sample consisted of 131 participants (age: $M = 11.38$, $SD = 0.53$; 60 boys, 71 girls). Participants had been matched based on gender beforehand and then randomly allocated to either the Restudy Condition ($n = 44$; 24 girls), the Summarizing Condition ($n = 47$; 27 girls) or the (Teaching on) Video Condition ($n = 40$; 20 girls). It was ensured through communication with the students' teachers and by selecting a text that comes from a book that is used one year later for our participants that the study was conducted at a point in time where the topic of the learning materials had not been covered in class.

3. Materials

All the materials were paper-based. The materials were created for the purpose of this study and adapted from an existing biology method "Biology for you" (Dutch: "Biologie voor jou") that is used in the first

[1] Students were asked to indicate how much time they invested in studying or generating the summary/video and to list everything that they had done when working on the homework assignment. Examples of non-compliance were not spending any time on reading the text, not spending any time on generating the summary or video, or asking parents for help.

year of secondary education (i.e., one year later for our participants).

Self-reported prior knowledge. A self-report prior knowledge test was used (cf. Fiorella & Mayer, 2013; Mayer & Moreno, 1998; Moreno & Mayer, 1999) because an objective measurement of prior knowledge might affect what students focus on during the study and generation phase. Participants were first asked to estimate their knowledge of photosynthesis on a scale of 1–5, with a 1 representing 'very low' and a 5 representing 'very high'. Next, participants were asked to mark whether each of five statements applied to them or not. These five statements were: (1) "I know exactly what photosynthesis is", (2) "I know exactly which processes are required for photosynthesis", (3) "I know exactly which processes are produced by photosynthesis", (4) "I know exactly why photosynthesis is important for humans", and (5) "I know exactly why photosynthesis is important for plants“.

Study text. Participants studied a text (808 words) on photosynthesis (see Appendix B). The text consisted of three pages. The first page addressed the characteristics and importance of leafs. Page two and three explained the process of photosynthesis and why photosynthesis is important for humans and animals. Each page also presented a picture, depicting the different components of a leaf (page 1), the processes involved in photosynthesis (page 2), or how the process of photosynthesis contributes to common foods that humans eat (page 3).

Posttest. The posttest was a conceptual knowledge test consisting of 10 open-ended items, and had a good reliability (α = .78). Example items are: 'Why is photosynthesis important for humans?' and 'why is photosynthesis and its products important for plants?'.

Perceived mental effort. Participants were asked to indicate how much mental effort they had invested the homework assignment and in each posttest task on a scale of 1 (very, very low effort) to 9 (very, very high effort; Paas, 1992).

Perceived learning enjoyment. Before the posttest, participants were asked to rate how enjoyable the homework assignment had been for them on a scale of 1 (very, very unenjoyable) to 9 (very, very enjoyable; Hoogerheide, Loyens, & Van Gog, 2014b, 2016).

Homework assignment check. Participants were required to indicate how much time they had invested in studying the text (Restudy, Summarizing, Video Condition) and in generating the summary (Summarizing Condition) or instructional video (Video Condition) and to list (in a step-by-step manner) exactly what they had done while working on their homework assignment.

3.1. Procedure

The study consisted of two sessions and a homework assignment. At least two weeks prior to the first session, the parents or caretakers of 8th grade primary school students were sent a consent form and information about the study. To increase the chance that parents or caretakers would consent, it was emphasized that the videos and summaries would only be seen by the teacher and that the activity would not affect the child's report card. Students with parental consent were, after being matched for gender, randomly allocated to one of the conditions before the first session.

The first session always took place on a Friday, in participants' own classroom, and lasted circa 25 min. The experimenter (the second author) first introduced himself and provided some basic information about the study. Afterwards, the experimenter distributed a consent form and asked all the students in the classroom who had received parental consent to read the form and to indicate (by signing the form) whether they would like to participate in the study or not. After the consent procedure, envelopes were distributed that each contained three different forms and had the name participants and condition (indicated by a letter) written on the front. Participants were first instructed to take out and complete the first form, which contained a short demographic questionnaire (e.g., age and gender) and the (self-report) prior knowledge test. Afterwards, they were instructed to place the first form back into the envelope.

Next, the experimenter instructed participants to take the second form from the envelope, which contained the learning activity instructions. The experimenter read the content of all three versions of the instruction forms aloud one by one (i.e., the verbal information provided by the experimenter mirrored the information written in the instruction form that students could take home). The experimenter explained that the class was divided into three different groups and that as part of a scientific study, each group would complete a homework assignment over the weekend of which the goal was to remember as much of the content of a text about photosynthesis as possible. Participants were instructed to learn by studying the text at home as often as they wanted (Restudy Condition) and then to write a summary about the text on paper (Summarizing Condition) or to teach the content of the text on video as if they were explaining to a fellow student (Video Condition). Each condition was informed to read the whole text at least one time, to stick to the instructions, and to not spend any longer than an hour in total on the homework assignment (to ensure that participants would not spend too much time on the homework assignment). The Video Condition was allowed to use any video-recording device. The Summarizing and Video Condition were asked to bring their generated product with them to school on Monday (for a check that the assignment had been completed by the teacher, but participants were not asked to hand in these products). Each form also contained a brief message for the parents or caretakers of the student, emphasizing that it was important that the student would stick to the instructions and would not receive any guidance from others, and reminding them that this homework assignment was part of a scientific study and that their child would not be graded. At the end of the first session, participants were provided with an opportunity to ask questions and it was made sure that participants placed the instruction form and study text in their bag and wrote down the details of their homework assignment in their agenda.

The second session always took place three days later. The experimenter again started with a general introduction, after which envelopes were distributed that contained two questionnaires and the posttest. Next, participants were instructed to take out the first questionnaire, which presented the perceived mental effort, learning enjoyment, and perceived time on task questions. After completing the first questionnaire, participants worked on the posttest. Each posttest item was followed by the perceived mental effort rating scale. Participants received 15 min to finish the posttest. Finally, participants completed the final questionnaire, which asked students to write down everything that they had done while working on their homework assignment. The experimenter emphasized the importance of being honest and that their answers would not have any consequences for them. After all students in the class were done, they were debriefed.

3.2. Data analysis

Self-reported prior knowledge scores could range from 1 to 10 points: 1 to 5 points depending on their answer on the knowledge rating scale and an additional point for each marked statement. As for the posttest, participants could earn 21 points in total. Each question could yield a score between 1 and 3 points (i.e., 1 × 1 point, 1 × 1.5 points, 5 × 2 points, 1 × 2.5 points, and 2 × 3 points), depending on how many "idea units" of the text were covered by the question. For instance, one question asked participants to describe the difference between how people/animals and plants gather the substances they eat. One point was awarded for correctly explaining how people/animals gather food (e.g., that people/animals feed on (parts of) other organisms, or that people/animals feed on plants and/or on animals) and one point for explaining how plants gather their food (e.g., that plants make their own food or that plants feed on glucose). Half points were given for partially correct answers. An independent rater and the second author scored the posttests of 21 participants (i.e., 16% of the total sample of 131 participants) to check for the reliability of the scoring. Results showed that the inter-rater reliability was very high, regardless of whether the intra-class correlation coefficient (ICC) was computed using the total posttest scores (ICC = 1.00), the test item scores (ICC = 1.00), or the idea unit scores (ICC = .98). Therefore, the remaining tests were scored by a single rater (i.e., the second author). Averages were computed for perceived effort invested in the 10 posttest tasks.

Unless otherwise indicated, our research questions were investigated with multi-level modeling analysis, because our experimental conditions were nested within classes ($j = 10$). To account for the nested data structure of our data, the lme4-package in R was used and a varying-intercept group effect model applied (Hox, 2010). The models considered participants to be nested within classes, so 'students' represented Level 1 and 'classes' represented Level 2. There was no missing data on Level 1 or 2. To test our hypotheses, the conditions were dummy-coded and three different multi-level regression analyses were conducted with class-membership as the group level variable and the contrast variables as predictor (for recent applications, see also: Lachner & Nückles, 2015). The first contrast compared the Video and Restudy Condition (Video = 1, Summarizing = 0, Restudy = −1), the second contrast compared the Summarizing and Restudy Condition (Video = 0, Summarizing = 1, Restudy = −1), and the third contrast compared the Video and Summarizing Condition (Video = 1, Summarizing = −1, Restudy = 0). A Bonferroni-correction was applied to correct for conducting multiple tests (adjusted alpha level of 0.0167, resulting from 0.050/3).

4. Results

Before addressing our hypotheses, it was checked whether the conditions were comparable before the study. A Chi square test showed no significant differences among conditions in terms of gender (which was to be expected given quasi-random assignment), X^2 (2) = .49, $p = .784$. Moreover, ANOVAs showed no differences among conditions with regards to age, $F(2, 128) = .06$, $p = .944$, $\eta^2_p = .001$, or self-reported prior knowledge, $F(2, 128) = 1.01$, $p = .367$, $\eta^2_p = .016$. Note that self-reported prior knowledge was very low across conditions with an average score of 1.59 on a scale of 1–10 (see Table 1).

It was also checked whether there were for differences among conditions in the reported time investment in studying the study text (ANOVA), in generating the summary vs. the video (independent-samples *t*-test), and in the learning phase overall (i.e., studying and generating combined for the Summarizing and Video Condition vs. only studying for the Restudy Condition; ANOVA). Results confirmed that there were no differences among conditions in reported time invested in studying the text, $F(2, 128) = 2.19$, $p = .116$, $\eta^2_p = .033$. There was no difference in reported time invested in generating the summary compared to generating the video either, $t(67.08) = 1.02$, $p = .314$, $d = 0.222$. However, as one might expect given the lack of difference in time spent studying the text, there was a significant main effect of condition on reported time investment in the learning phase as a whole, $F(2, 128) = 31.79$, $p < .001$, $\eta^2_p = .332$, with Bonferroni-corrected post-hoc tests showing that, compared to the Restudy Condition, students reported more time investment in the learning phase as a whole in the Summarizing Condition, $p < .001$, $d = 1.514$, and Video Condition, $p < .001$, $d = 1.585$. There was (again to be expected, given the study time and generation time analyses) no significant difference between the Summarizing and Video Condition, $p = .117$, $d = 0.389$.

4.1. Does teaching on video as homework affect test performance?

The multi-level analysis showed that, as expected, students in the Video Condition significantly outperformed those in the Restudy Condition on the posttest, $B = 1.49$, $SE = 0.45$, $p = .002$, 95% CI [0.600, 2.362]. In contrast to our hypothesis, however, there was no performance difference between students in the Video and Summarizing Condition, $B = 0.54$, $SE = 0.46$, $p = .240$, 95% CI [-0.358, 1.435] and those in the Summarizing Condition did not outperform the Restudy Condition, $B = 0.85$, $SE = 0.45$, $p = .057$, 95% CI [-0.016, 1.719]. Overall, these results showed that generating an instructional video was more effective than restudy, while summarizing was not.[2]

4.2. Does teaching on video as homework affect perceived mental effort?

With regard to self-reported effort investment in the learning phase, results showed that in line with our hypothesis, compared to the Restudy Condition, students in the Video Condition, $B = 0.53$, $SE = 0.20$, $p < .001$, 95% CI [0.337, 1.117], and the Summarizing Condition, $B = 0.57$, $SE = 0.19$, $p = .004$, 95% CI [0.185, 0.946], reported to have invested significantly more effort. There was no significant difference between the Video Condition and the Summarizing Condition, $B = 0.11$, $SE = 0.21$, $p = .599$, 95% CI [-0.296, 0.511].

As for perceived effort invested in completing the posttest, there were no differences among conditions (Video vs. Restudy Condition: $B = -0.33$, $SE = 0.16$, $p = .038$, 95% CI [-0.647, −0.021]; Summarizing vs. Restudy Condition: $B = -0.16$, $SE = 0.16$, $p = .300$, 95% CI [-0.465, 0.142]; Video vs. Summarizing Condition: $B = -0.15$, $SE = 0.16$, $p = .334$, 95% CI [-0.465, 0.157]).

4.3. Does teaching on video as homework affect perceived learning enjoyment?

As expected, students in the Video Condition reported significantly higher levels of learning enjoyment than students in the Restudy Condition, $B = 0.53$, $SE = 0.19$, $p = .006$, 95% CI [0.152, 0.897], and students in the Summarizing Condition, $B = 0.58$, $SE = 0.18$, $p = .002$, 95% CI [0.215, 0.940]. Enjoyment of summarizing did not differ significantly from restudying, $B = -0.07$, $SE = 0.19$, $p = .711$, 95% CI [-0.437, 0.296].

4.4. Explorative follow-up analyses: do perceived learning enjoyment and mental effort mediate the effect of teaching on video on test performance?

As the Video Condition showed greater test performance, perceived learning enjoyment, and perceived effort investment in the learning phase than the Restudy Condition, it was explored whether the effectiveness of teaching on video for test performance was mediated by reported learning enjoyment and effort investment. Two causal mediation analyses for multi-level data were conducted via the mediation package implemented in R, using the video vs. restudy contrast (Video = 1, Summarizing = 0, Restudy = −1) as predictor and test performance as the dependent variable. To derive a 95%-bias-corrected confidence interval for the indirect effect, 10,000 bootstrap samples were used. The main findings of these mediation analyses can be found in Fig. 1.

Results of the mediation analyses showed that there was no support for the idea that reported effort investment in the learning phase could explain why students in the Video Condition outperformed those in the

[2] Note that the statistical pattern stays the same if self-reported prior knowledge is included as a covariate in the multi-level analysis.

Table 1
Mean (SD) of all outcome variables per condition.

	(Teaching on) Video Condition	Summarizing Condition	Restudy Condition
Self-reported prior knowledge *(range 1 to 10)*	1.78 (1.56)	1.40 (0.77)	1.61 (1.26)
Posttest performance *(range 0 to 21)*	12.93 (4.17)	11.73 (4.15)	9.99 (4.06)
Perceived mental effort investment in learning *(range 1 to 9)*	4.75 (1.94)	4.47 (1.76)	3.32 (1.81)
Perceived mental effort investment in posttest *(range 1 to 9)*	4.18 (1.59)	4.52 (1.43)	4.85 (1.39)
Perceived learning enjoyment *(range 1 to 9)*	5.58 (1.96)	4.38 (1.94)	4.52 (1.59)
Perceived time investment in studying the text	11.60 (8.44)	8.46 (5.73)	11.18 (8.80)
Perceived time investment in generating the video vs. summary	22.24 (15.61)	19.27 (10.65)	
Perceived time investment overall (i.e., studying + video/summary)	33.84 (18.19)	27.73 (12.71)	11.18 (8.80)

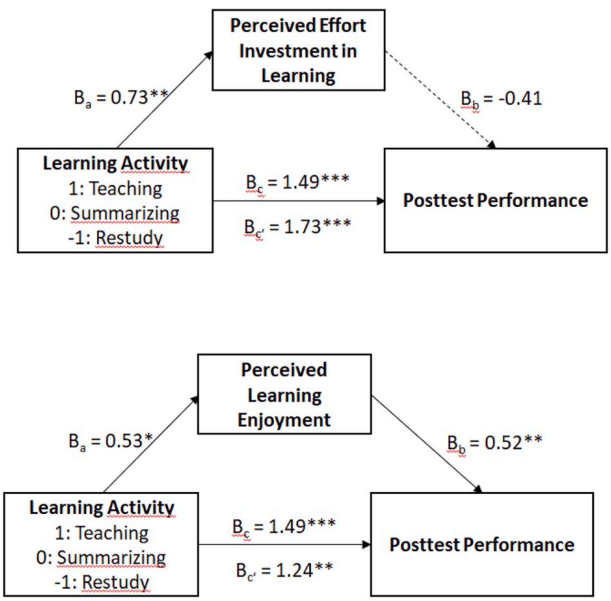

Fig. 1. Main findings of the mediation analysis. Numbers represent unstandardized path coefficients for the direct and total effects. Solid lines mark significant relations; dashed lines mark non-significant relations. $^{*}p < .05$, $^{**}p < .01$.

Restudy Condition on the posttest, as the indirect effect via mental effort was not significant, $a \times b = -0.15$, $p = .42$, 95% CI [-0.581, 0.221]. However, there was a significant indirect effect via learning enjoyment, $a \times b = 0.32$, $p = .01$, 95% CI [0.055, 0.698], suggesting that a significant part of the effect of condition on test performance could be explained by enjoyment.

5. Discussion

The main aim of this study was to investigate whether, after an initial study phase, teaching the content of a study text to a fictitious peer student on camera (i.e., teaching on video) would be a more effective homework activity for primary school students than restudying or summarizing. Effects on perceived effort investment were also examined because in combination with test performance, perceived mental effort provides insight on the efficiency of instructional conditions (Van Gog & Paas, 2008), and on perceived learning enjoyment, which is an important aspect of intrinsic motivation (Deci & Ryan, 1985) and a potential indicator of the use of learning strategies outside of experimental settings (Yi & Hwang, 2003).

In line with our hypotheses, generating a teaching video was perceived as more effortful and improved test performance compared to restudying. Thus, our findings conceptually replicate and extend results of studies on the effectiveness of teaching on video in comparison to restudying with adolescents and adults in controlled settings (e.g., Fiorella & Mayer, 2014; Hoogerheide et al., 2014a). In contrast to our hypothesis, the teaching on video condition did not outperform the summarizing condition; however, summarizing did not lead to better test performance than restudying, while teaching on video did. The perceived learning enjoyment results showed that students who generated a teaching video also reported higher levels of learning enjoyment than those who had generated a summary or restudied, while summarizing was not more enjoyable than restudying. Exploratory mediation analyses suggest that perceived learning enjoyment (but not perceived effort invested in learning) can at least in part explain why teaching on video improved test performance compared to restudying.

Regarding the mechanisms responsible for the benefits of teaching on video, our results seem to suggest that it is not only a matter of generative activities. Summarizing did not lead to better test performance than restudy, yet teaching did, which suggests that the key does not merely lie in generative processing (e.g., organizing the material into a coherent narrative; Fiorella & Mayer, 2016). Based on the generative learning hypothesis, one would expect both generative learning strategies (i.e., teaching and summarizing) to result in better test performance than restudying.

Rather, the key seems to lie in the social presence hypothesis, which states that the effectiveness of learning-by-teaching depends on the degree to which students are aware of the (imagined) audience during teaching (Hoogerheide, Deijkers et al., 2016). This could either affect learning outcomes directly, for instance through increased arousal, or indirectly, by affecting the generative processes that take place. Whereas some generative processes likely occur in teaching and summarizing (e.g., focusing on the main ideas of the text and repairing knowledge gaps), teaching might also promote generative processes that are not a part of summarizing (e.g., monitoring whether the explanations would be understandable for the audience). Next to cognitive processes, social presence might also have motivational effects, as evidenced by our learning enjoyment results; being aware of a potential audience might motivate and engage students to, for instance, do their best to ensure that a message is as accurate and complete as possible (Coleman, Brown, & Rivkin, 1997; Webb, 1989).

However, an alternative explanation both regarding effectiveness and enjoyment might lie in the modality difference between teaching on video and summarizing (i.e., speaking vs. writing). Students were instructed to generate written summaries because written summaries are much more prevalent in educational settings than oral summaries and the effects of written summaries much better documented by research (Dunlosky et al., 2013; Fiorella & Mayer, 2016). However, there are differences between speaking and writing that could influence how much students learn. On the one hand, writing could improve learning compared to speaking because written discourse involves more planning and monitoring and allows for less irrelevant information to be produced; on the other hand, students may learn more from speaking than writing because speaking is generally faster and associated with higher levels of social involvement than writing (Chafe, 1982; Forrin & MacLeod, 2018; Grabowski, 2007; Horowitz & Newman, 1964; Kellogg, 2007).

The findings from the present study are in line with other studies showing more beneficial effects of video or oral explanations compared to writing explanations, which also seem to suggest that modality matters. Hoogerheide, Deijkers and colleagues (2016) showed that teaching to a fictitious peer student on video resulted in better learning outcomes than restudy, yet teaching in writing did not. Lachner et al. (2018) found no differences between having students provide written and oral explanations on a conceptual knowledge posttest, but those in the oral explaining condition performed significantly better on a transfer posttest. Note that the findings of Hoogerheide, Loyens, and Van Gog (2016) and Lachner et al. (2018) could also be explained by feelings of social presence, because oral discourse is typically characterized by higher levels of social involvement than written discourse (Chafe, 1982; Redeker, 1984).

An unexpected finding that deserves more discussion is that summarizing was not more effective than restudy and even less cognitively efficient in the sense that equal performance was attained with significantly more perceived effort invested in learning (Van Gog & Paas, 2008). Although summarizing often improves learning (e.g., Doctorow et al., 1978; King, 1992; Wittrock & Alesandrini, 1990), the robustness of summarizing has been questioned (e.g., Dunlosky et al., 2013). One line of research suggests that to be able to reap the benefits of summarizing, students might need training beforehand to learn how to generate accurate and complete summaries (Bean & Steenwyk, 1984; Bednall & Kehoe, 2011; Garner, 1982). Younger students might particularly benefit from training, because they tend to struggle with identifying the main ideas in the text and write low quality summaries with much of the same wording and structure as the original text (e.g., Arnold et al., 2017; Brown & Day, 1983; Brown, Day, & Jones, 1983). If that training explanation holds true, then it becomes an important question why the same principle does not seem to apply to teaching on video, which so far has been shown to consistently improve test performance compared to studying for a test (e.g., Fiorella & Mayer, 2014; Hoogerheide et al., 2014a). If social presence is a key working mechanism of learning-by-teaching, another interesting question for future research would be whether increasing feelings of social presence during summarizing would also improve learning outcomes.

Strengths of the current study were: the comparison of teaching on video to both restudying and summarizing, the sample (i.e., primary school students), the objective posttest (i.e., no perceived learning measure), and the ecological validity of the homework activity. A limitation of our homework assignment is that treatment fidelity cannot be guaranteed. Various measures were taken to increase the likelihood that students would follow our instructions (e.g., by giving students a form to take home with detailed instructions for the homework assignment as well as message for parents/caretakers) and to be able to detect and remove those students from the sample who did not follow our instructions (e.g., by asking students to indicate how much time they invested in the homework assignment and to list everything done while working on the homework assignment).

Another limitation is that students' summaries and teaching videos could not be analyzed, because students were not asked to hand their generated product in to increase the chance of parental consent. Had students been asked to hand in their summaries and videos, it could be checked whether the conditions differed in the extent to which they engaged in generative processing and whether the quality (i.e., accuracy and completeness) and quantity (i.e., number of words) of the summaries/explanations mediated our test performance results. Another potential limitation, which future research should address by investigating effects over time, is that creating a video may have been more enjoyable and more effective because it was a novel homework activity. Lastly, the self-report prior knowledge test is a limitation. Despite the fact that prior knowledge was very low (average score of 1.59 out of 10) and that students' teachers indicated that the topic of the learning materials had not been a part of the curriculum yet, subjective measures of knowledge can be inaccurate (Kruger & Dunning, 1999).

In sum, our findings indicate that generating a teaching video is an effective and enjoyable homework activity for primary school students. These results are very relevant for educational practice, where there is a growing interest in the effects of instructing students to learn by generating their own instructional videos (e.g., Lenhart, 2012; Spires et al., 2012), yet a paucity of studies with a control condition that do not solely rely on self-report data. That generating a teaching video works in the form of a homework assignment is particularly interesting, because, despite the fact that homework accounts for a substantial proportion of students' study time in most countries around the world, there is an ongoing debate about whether homework "works" (Cooper, Robison, & Patall, 2006; Dettmers, Trautwein, Lüdtke, Kunter, & Baumert, 2010; Trautwein, Lüdtke, Schnyder, & Niggli, 2006). Research has shown that the relationship between homework and achievement is especially weak for young children, who tend to struggle keeping their attention sustained because of all the distractions present in the home environment (Cooper, Robinson, & Patall, 2006). As such, identifying enjoyable and effective homework strategies is important. Future research should further investigate the effects of instructing students to learn by generating instructional videos in applied settings, as well as further uncover why generating instructional (teaching) videos is an effective and enjoyable strategy for learning.

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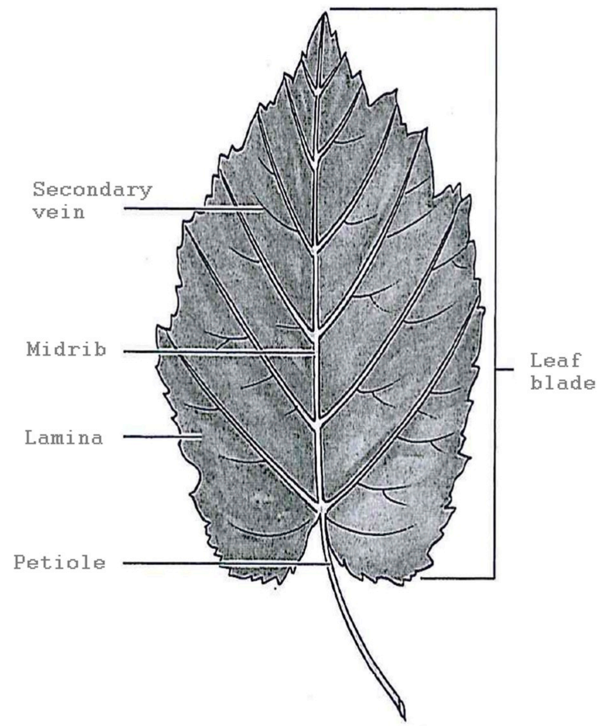
Appendix A. Power Analysis

A multilevel simulation study was performed with the lme4 package (version 1.1–17) to determine how many participants and classes would be needed to be able to reliably detect the medium to large effect of teaching on video ($d = 0.70$) found by Hoogerheide et al. (2014a) and Fiorella and Mayer (2013, 2014). It was decided to recruit at least 120 participants spread over 10 classes, because a simulation with 400 data sets with clustered data ($j = 10$ classes) and the exact two-level model reported in the manuscript showed that with 12 participants per cluster, the power would be 87.75%.

Appendix B. Study Text (Translated from Dutch)

Most trees, plants, and flowers have leaves. Leaves are very important, not only for the plants themselves, but also for animals and people, because of a process called photosynthesis. In this text you will learn what leaves look like, which functions leaves have, what photosynthesis is, and why photosynthesis is so important for plants, animals, and people.

Most trees, plants, and flowers have leaves. A leaf consists of a petiole and a leaf blade. The petiole connects the leaf to the stem. The flat part of the leaf is called the leaf blade (see Picture 1). The leaf blade contains many veins. The midrib usually runs through the center of the leaf. The branches of the midrib are called the secondary veins. These branch out and become smaller veins. Veins are responsible for the firmness of the leaf and take care of the transport of water and nutrients. All the material between the veins is called the lamina.



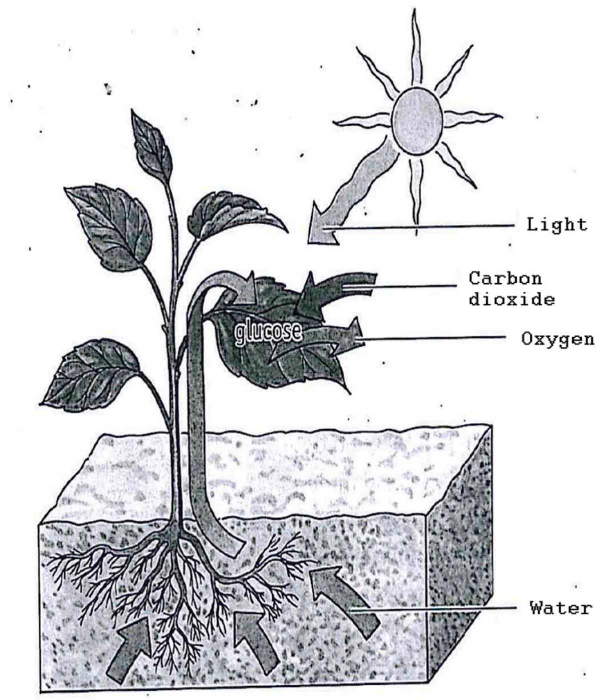
Picture 1. The components of a leaf.

*The **importance** of leaves*

All organisms (= everything that lives) need substances to stay alive and to grow. People and animals gather these substances from the air that they breathe and the food that they eat. Animals and people feed themselves on other organisms or on parts of other organisms. The foods that people eat can origin from plants or from animals. This food supplies people with the substances that make up our body. Plants, however, do not feed on other organisms. Plants supply the substances that they are made from themselves. To accomplish this, plants use substances from the ground and from the air. Leaves are especially important for supplying the substances that plants are made from.

Photosynthesis

In plants, a process takes place that is called photosynthesis. Photosynthesis mainly happens in the leaves. During photosynthesis, the substance glucose is made. Glucose is like a type of sugar and a very important substance for plants. To make glucose, plants need other substances, which include the substances that plants are made from. In a way, plants make their own food. This food is glucose.



Picture 2. Photosynthesis in a plant

Picture 2 shows a schematic overview of the process of photosynthesis. Water, carbon dioxide, and light are needed for photosynthesis. Through the process of photosynthesis, glucose and oxygen are made. So you can summarize the process of photosynthesis as follows: water + carbon dioxide + light → glucose + oxygen.

All the substances needed for photosynthesis are shown left of the arrow. All the substances that are created are depicted right of the arrow.

What substances do plants need for photosynthesis?

To make glucose, plants need certain substances. One of these substances is water. The roots of a plant take the water from the soil and the water is transferred to the leaves. The water arrives in the lamina via the veins.

The other substance that is needed for photosynthesis comes from the sky: carbon dioxide. The leaves have small openings to take carbon dioxide from the air. Carbon dioxide is a gas. You cannot see carbon dioxide with your eyes, but you do know it. The little bubbles in lemonade or coke are made from carbon dioxide.

Photosynthesis also requires light. Plants that are always in the dark die after a couple of weeks. In these plants, photosynthesis cannot happen.

Which substances are created by photosynthesis?

Photosynthesis does not only create glucose, but also oxygen. Oxygen is a gas. Oxygen is in the air, like carbon dioxide. Oxygen travels from the plant to the air via small openings in the leaves.

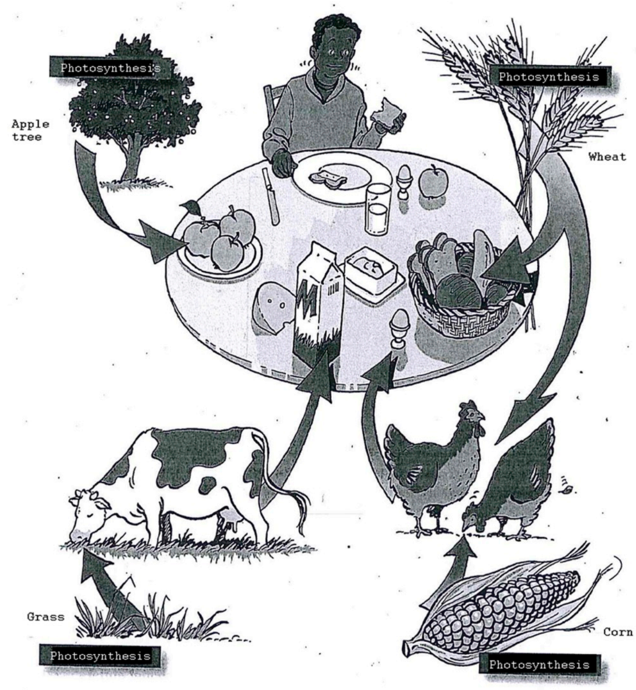
Water plants take carbon dioxide from the water and give oxygen back to the water. When a water plant gives a lot of oxygen to the water, you can sometimes see this by the little bubbles that ascend from the plant.

Where does photosynthesis occur?

Photosynthesis can only happen with chloroplasts. Chloroplasts are the parts in a cell of a plant responsible for the green color. Photosynthesis mostly takes place inside green leaves, but also in other green parts of a plant. So in plants with green stems, photosynthesis happens mostly in the leaves, but can also take place in the green stems.

Het use of photosynthesis for people and animals.

Photosynthesis is also important for animals and humans. Just about everything that people eat, comes from plants. A piece of meat for example may come from a cow, but that cow ate grass. An egg may come from a chicken, but that chicken ate corn (see Picture 3).

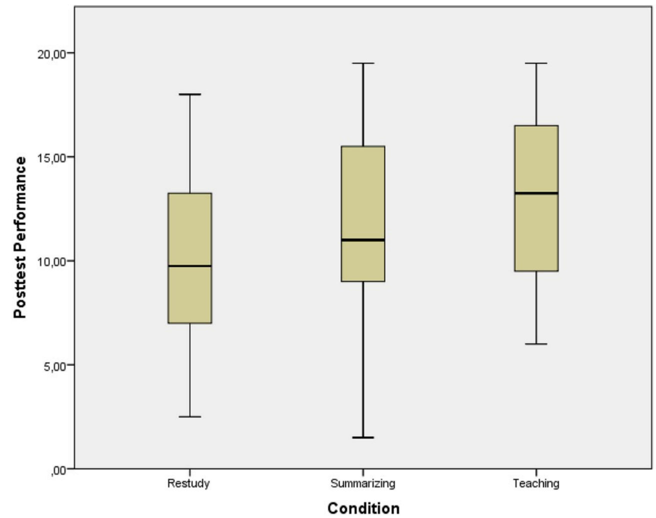


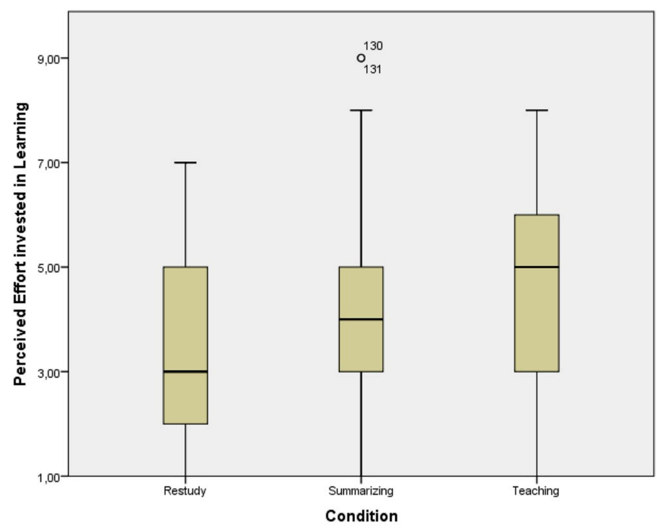
Picture 3. Food that people eat that is created by photosynthesis

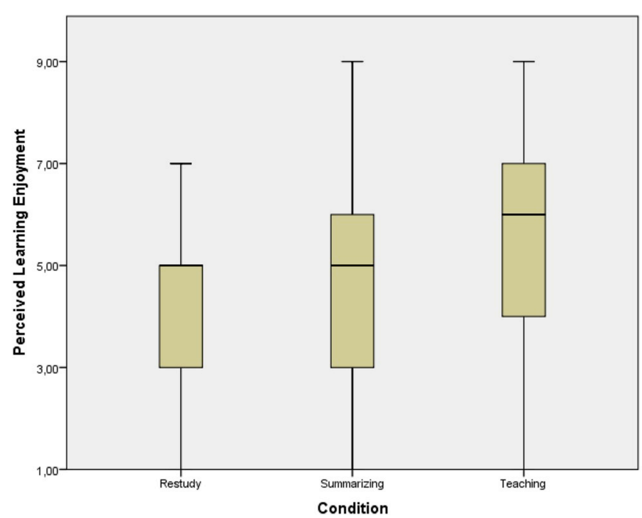
Thanks to photosynthesis, earth keeps being supplied with new food and oxygen. People and animals use oxygen. Because photosynthesis creates oxygen, enough oxygen remains in the air. Without photosynthesis the oxygen in the air would slowly disappear. People and animals would not be able to live without enough oxygen.

Appendix C. Boxplots of Posttest Performance (top), Perceived Effort Invested in Learning (middle), and Perceived Learning Enjoyment (bottom) per Condition.

Note that there are two outliers because two participants in the summarizing condition reported that they had invested "(9) very, very high effort" in the homework assignment (on a scale of 1–9). It was decided to include these scores, because they fall within 3 standard deviations from their condition mean (z-scores: 2.58) and removing these two participants from the sample would not change the findings (i.e., Summarizing/ Video > Restudying).







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