REVIEW ARTICLE

Learning-by-Teaching Without Audience Presence or Interaction: When and Why Does it Work?

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Abstract
Teaching the contents of study materials by providing explanations to fellow students can be a beneficial instructional activity. A learning-by-teaching effect can also occur when students provide explanations to a real, remote, or even fictitious audience that cannot be interacted with. It is unclear, however, which underlying mechanisms drive *learning by non-interactive teaching effects* and why several recent studies did not replicate this effect. This literature review aims to shed light on *when* and *why* learning by non-interactive teaching works. First, we review the empirical literature to comment on the different mechanisms that have been proposed to explain why learning by non-interactive teaching may be effective. Second, we discuss the available evidence regarding potential boundary conditions of the non-interactive teaching effect. We then synthesize the available empirical evidence on processes and boundary conditions to provide a preliminary theoretical model of when and why non-interactive teaching is effective. Finally, based on our model of learning by non-interactive teaching, we outline several promising directions for future research and recommendations for educational practice.

Keywords Learning by teaching · Learning by explaining · Generative learning · Teaching on video

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Introduction

Seminal research documented that learning-by-teaching, that is explaining the contents of study materials to others, can be a beneficial instructional activity that improves the understanding of the person who teaches (Chi et al., 2001; Duran & Topping, 2017; Plötzner et al., 1999; Roscoe & Chi, 2008; Webb et al., 1995; see Duran, 2017 for an overview). Most studies investigating learning-by-teaching, entailed seeing and interacting with an audience (of one or more other people; Bargh & Schul, 1980; Cohen et al., 1982). Recently, however, the effectiveness of learning-by-teaching has also been demonstrated without actual audience presence (i.e., teaching to fictitious or imagined fellow student(s); e.g., Fiorella & Mayer, 2013; Hoogerheide et al., 2014). We will refer to this activity as learning by non-interactive teaching. Learning by non-interactive teaching is relevant for educational practice, as it can be realized as an individual study activity (e.g., during homework) that does not necessitate the presence of or interaction with a teacher or a fellow student. Although the empirical evidence for the effectiveness of non-interactive teaching scenarios has increased in recent years (see Table 1), it is still largely unclear which underlying mechanisms drive the non-interactive teaching effect. Moreover, some studies showed null-effects or even found detrimental effects of non-interactive teaching on (certain measures of) students' learning (e.g., Fiorella et al., 2017; Hoogerheide et al., 2016a; Lachner et al., 2021; Roscoe & Chi, 2008). These mixed findings are likely a result of different study characteristics, which may indicate that there are boundary conditions that determine whether non-interactive teaching is effective or not.

Against this background, this literature review aims to shed light on when and why learning by non-interactive teaching works. We explicitly decided against a meta-analytical review in favor of a theoretical literature review, as our main aim was not to test the effectiveness of learning by non-interactive teaching (see Kobayashi, 2019; Lachner et al., 2021, for recent meta-analytical evidence). Rather, we aim to provide a theoretical model on the underlying cognitive and motivational processes of non-interactive teaching as well as to detail potential boundary conditions that might constrain the effectiveness of non-interactive teaching.

To provide a considerable database for our theoretical review, we searched for English empirical articles in the Google Scholar and the Web of Science data bases with the following search terms ("learning by teaching" | "learning-by-teaching") and ("fictitious" | "non-present"). The use of these search terms was preceded by an initial screening phase, in which we examined whether the search terms were used in seminal articles on non-interactive teaching (Alexander, 2020). Articles were included if they (a) comprised an intervention in which learning by non-interactive teaching (e.g., teaching a fictitious or non-present person, providing an instructional explanation to a non-present person) was implemented, (b) followed an experimental research design (quasi-experimental, experimental), and (c) was published in a peer-reviewed academic journal.

We decided not to include literature on teachable agents, as despite some similarities, there are several important differences between (research on) the act of

Table 1 Effects of non-interactive teaching on learning outcomes

Authors	Materials and participants	Experimental design	Effects on learning outcomes
Published studies			
Fiorella and Mayer (2013)	Multimedia learning (Doppler effect), university students	**Experiment 1 and 2**: 3×1-between-subjects design: control vs. teaching expectancy vs. non-interactive teaching (video)	**Experiment 1** (immediate test): control < teaching expectancy ($d=0.59$); control < non-interactive teaching ($d=0.82$) **Experiment 2** (delayed test): control < non-interactive teaching ($d=0.79$)
Fiorella and Mayer (2014)	Multimedia learning (Doppler effect), university students	**Experiment 2**: 2×2-between-subjects design: expectancy (teaching vs. testing) vs. non-interactive teaching (teaching (video) vs. restudy) **Boundary condition:** teaching expectancy	**Experiment 2** (delayed test): teaching expectancy + non-interactive teaching > restudy ($d=0.56$)
Fiorella et al. (2018)	Instructional video (electric circuits), university students	**Experiment 2**: 2×2-between-subjects design: study video (first-person perspective vs. third-person perspective) vs. non-interactive teaching (teaching vs. no-teaching) on video	**Experiment 2:** • Recognition test: ns • Assembly test: ns
Fiorella and Kuhlmann (2020)	Expository text (respiratory system), university students	2×2-between-subjects design: non-interactive teaching (yes (video) vs. no) vs. drawing (yes vs. no)	• Recall: non-interactive teaching + drawing > non-interactive teaching-only ($d=0.96$); non-interactive teaching + drawing > drawing-only ($d=0.62$); non-interactive teaching + drawing > restudy ($d=1.15$); non-interactive teaching-only > restudy; drawing-only > restudy ($d=0.64$) • Transfer: non-interactive teaching + drawing > non-interactive teaching-only ($d=0.59$); non-interactive teaching + drawing > restudy ($d=1.34$); non-interactive teaching-only > restudy ($d=0.76$); drawing-only > restudy ($d=0.89$) Effect of condition on combined posttest was mediated by the number of elaborations
Fukaya (2013)	Experiment 1: Expository texts (everyday devices), university students	**Experiment 1 and 2**: 3×1-between-subjects design: control vs. teaching expectancy vs. non-interactive teaching (oral)	**Experiment 1:** • Comprehension: ns **Experiment 2:** • Comprehension: ns

Table 1 (continued)

Authors	Materials and participants	Experimental design	Effects on learning outcomes
Hoogerheide et al. (2014)	Expository text (syllogistic reasoning) Experiment 1: secondary students Experiment 2: university students	**Experiment 1 and 2:** 3×1-between-subjects design: testing expectancy vs. teaching expectancy vs. non-interactive teaching (video)	**Experiment 1** (secondary students): • Recall: ns • Transfer: teaching expectancy < non-interactive teaching ($d=0.75$) • testing expectancy < non-interactive teaching ($d=0.79$) **Experiment 2** (university students): • Recall: testing expectancy < non-interactive teaching ($d=1.10$); testing expectancy < teaching expectancy ($d=0.75$) • Transfer: testing expectancy < non-interactive teaching ($d=0.70$)
Hoogerheide et al. (2016a)	Expository text (syllogistic reasoning), university students	**Experiment 1:** 2×2-between-subjects design: expectancy (teaching vs. testing) vs. non-interactive teaching (teaching (written) vs. restudy) **Boundary condition:** teaching expectancy **Experiment 2:** 3×1-between-subjects design: restudy vs. non-interactive teaching (written) vs. non-interactive teaching (video)	**Experiment 1:** • Recall: ns • Transfer: ns **Experiment 2:** • Recall: restudy < non-interactive teaching (video) ($d=0.43$) • Transfer: ns
Hoogerheide et al. (2019a)	Worked examples (electric circuits), university students	2×1-between-subjects design: non-interactive teaching (video) vs. restudy	• Recall: non-interactive teaching > restudy ($\eta_p^2 = .69$) • Transfer: non-interactive teaching > restudy ($\eta_p^2 = .65$), moderated by prior knowledge
Hoogerheide et al. (2019b)	Expository text (photosynthesis), primary students	3×1-between-subjects design: non-interactive teaching (video) vs. summary (written) vs. restudy	• Comprehension: restudy < non-interactive teaching ($d=0.71$), mediated by enjoyment

Table 1 (continued)

Authors	Materials and participants	Experimental design	Effects on learning outcomes
Jacob et al. (2020a)	Expository texts (low-complexity text: reproduction; high complexity text: immunology), university students	2×3-subjects design: text difficulty (low-complexity vs. high-complexity text) as within-subject factor and experimental condition (audio non-interactive teaching vs. written non-interactive teaching vs. retrieval) as between-subjects factor **Boundary condition:** modality, learning materials	**Low-difficult text** • Recall: ns • Transfer: ns **High-difficult text** • Recall: ns • Transfer: non-interactive teaching (oral + written) > retrieval ($d=0.36$); oral teaching > written teaching ($d=0.32$); serially mediated by the number of personal references and the provision of concepts within the explanations
Jacob et al. (2021)	Expository text: Immunology University students	4×1-between-subjects design: non-interactive teaching (oral) vs. non-interactive teaching (written) vs. non-interactive teaching (written chat) vs. retrieval **Boundary condition:** modality, induced social presence	• Recall: ns • Transfer: ns • Indirect effect of enjoyment
Koh et al. (2018)	Multimedia learning (Doppler effect) university students	4×1-between-subjects design: non-interactive teaching (video) + retrieval vs. non-interactive teaching-only (video) vs. retrieval-only vs. control	• Comprehension: non-interactive teaching + retrieval > control ($d=0.84$); retrieval-only > control ($d=0.91$); non-interactive teaching + retrieval > non-interactive teaching-only ($d=0.58$); retrieval-only > non-interactive teaching-only ($d=0.65$)
Lachner et al. (2018)	Multimedia learning (combustion engines), university students	2×1-between-subjects design: non-interactive teaching (audio) vs. non-interactive teaching (written) **Boundary condition:** modality	• Recall: ns • Transfer: non-interactive audio teaching > non-interactive written teaching ($d=0.67$), mediated by the number of elaborations

Table 1 (continued)

Authors	Materials and participants	Experimental design	Effects on learning outcomes
Lachner et al. (2020)	Multimedia learning (combustion engines), university students	**Experiment 1:** 3 × 1-between-subjects design: after-study non-interactive teaching (video) vs. in-between non-interactive teaching (video) vs. oral retrieval **Experiment 2:** 2 × 2-between-subjects design: timing (in-between vs. after-study) vs. activity (teaching (video) vs. written retrieval) **Boundary condition:** timing	**Experiment 1:** • Recall: in-between non-interactive teaching > after-study non-interactive teaching (η_p^2 = .06), mediated by increases of monitoring and meta-comprehension • Transfer: ns **Experiment 2:** • Recall: in-between non-interactive teaching > in-between retrieval practice > after-study non-interactive teaching > after-study retrieval practice (η_p^2 = .05) Transfer: ns
Lachner et al. (2021)	Experiment 1: Multimedia learning (bacterial endocarditis), University students Experiment 2: four expository texts on educational technology, pre-service teachers	**Experiment 1:** 4 × 1-between-subjects design (written, laboratory): non-interactive teaching vs. self-explaining vs. retrieval vs. control **Experiment 2:** 4 × 1-within-subjects design (written, laboratory): non-interactive teaching vs. self-explaining vs. retrieval vs. control	**Experiment 1:** • Recall: ns • Transfer: ns **Experiment 2:** • Recall: ns • Transfer: self-explaining > retrieval (d = 0.88; self-explaining > control (d = 0.59); self-explaining > non-interactive teaching (d = 0.59)
Lachner and Neuburg (2019)	Multimedia learning (photovoltaic) university students	2 × 1-between-subjects design: non-interactive teaching (written) + feedback vs. non-interactive teaching-only (written)	• Recall: ns • Transfer: written non-interactive teaching + feedback > written non-interactive teaching-only (η_p^2 = .12), mediated by the level of global cohesion of the explanations
Rhoads (2019)	Motor skill learning (free throws, basketball), adults	**Experiment 2:** 2 × 2-between-subjects design: Expertise (novice vs. experienced) vs. non-interactive teaching (yes vs. no) on video	**Experiment 2** • Immediate posttest: ns • Delayed posttest: ns
Rhoads et al. (2019)	Motor skill learning (golf putting) adults	2 × 2-between-subjects design: teaching expectancy (yes vs. no) vs. non-interactive teaching (yes vs. no) on video **Boundary condition:** teaching expectancy	• Posttest (blind): ns • Posttest (unblind): ns

Table 1 (continued)

Authors	Materials and participants	Experimental design	Effects on learning outcomes
Roscoe and Chi (2008)	Expository text (human eye), university students	3×1-between-subjects design: teaching present tutee vs. non-interactive teaching (video) vs. self-explaining	• Comprehension: self-explaining > teaching present tutee ($d=1.13$); self-explaining > non-interactive teaching ($d=1.64$)
van Brussel et al. (2021)	Computer-based direct instruction (critical thinking), pre-service teachers	3×1-between-subjects design: non-interactive teaching (video) vs. teaching expectancy vs. restudy	• Comprehension: ns • Transfer: ns
Unpublished studies			
Hoogerheide, Renkl, et al. (2020)	Worked examples (electric circuits), university students	**Experiment 1:** 3×1-between-subjects design: non-interactive teaching fictitious student (video) vs. non-interactive teaching real student (video) vs. restudy **Experiment 2:** 3×1-between-subjects design: non-interactive teaching fictitious student (video) vs. non-interactive teaching real student (video) vs. restudy **Boundary condition:** induced social presence	**Experiment 1:** • Recall: ns • Transfer: restudy > non-interactive teaching to real student ($d=0.70$); non-interactive teaching fictitious student = non-interactive teaching real student; non-interactive teaching fictitious student = restudy • Arousal: non-interactive teaching real student > restudy ($d=0.73$); non-interactive teaching real student > non-interactive teaching fictitious student ($d=0.64$); non-interactive teaching fictitious student = restudy **Experiment 2:** • Posttest (retention + transfer): restudy > non-interactive teaching real student ($d=0.60$); non-interactive teaching fictitious student = non-interactive teaching real student; non-interactive teaching fictitious student = restudy
Hoogerheide, Lachner, et al. (2020)	Worked examples (electric circuits), university students	**Experiment 1:** 3×1-between-subjects design: non-interactive teaching to one student (video) vs. non-interactive teaching to four students (video) vs. restudy **Boundary condition:** induced social presence	• Posttest (retention + transfer): ns

Table 1 (continued)

Authors	Materials and participants	Experimental design	Effects on learning outcomes
Jacob et al. (2020b)	Technology-enhanced lesson about photosynthesis, secondary students	3×1-between-subjects design: non-interactive teaching (audio) vs. non-interactive teaching (written) vs. retrieval **Boundary condition:** modality, ability beliefs	• Recall: ns; moderation by self-concept: non-interactive teaching more beneficial than retrieval for low self-concept students Transfer: ns
Kawashimo and Fukaya (2020)	Math classes (polygon interior angles), primary students	2×1-between-subjects design: non-interactive teaching (oral) vs. retrieval practice (written)	• Recall: non-interactive teaching > retrieval practice ($d = 1.08$) • Transfer: ns
Richter et al. (2020)	Simulation-based learning (photosynthesis), university students	3×1-between-subjects design: direct instruction vs. problem-solving vs. problem-solving + non-interactive teaching (video) **Boundary condition:** ability beliefs	• Comprehension: direct instruction > (problem-solving = problem-solving + non-interactive teaching) ($\eta_p^2 = .10$) • Transfer: direct instruction > (problem-solving = problem-solving + non-interactive teaching) ($\eta_p^2 = .04$)
Waldeyer et al. (2020)	Lecture (social norms), university students	3×1-between-subjects design: non-interactive teaching (video) vs. non-interactive teaching (audio) vs. restudy	• Recall: restudy > non-interactive video teaching = non-interactive audio teaching ($d = .70$) • Comprehension: non-interactive video teaching = non-interactive audio teaching > restudy ($d = 0.54$)
Wassenburg et al. (2020)	Expository text (Doppler effect), university students	4×1-between-subjects design: non-interactive teaching (video) vs. non-interactive teaching (audio) vs. self-explaining (video) vs. restudy	• Comprehension: restudy > non-interactive audio teaching ($d = 0.55$); restudy > non-interactive video teaching ($d = 0.62$) • Transfer: restudy > non-interactive video teaching ($d = 0.65$); restudy > self-explaining ($d = 0.74$)

teaching a teachable agent and non-interactive teaching that make it difficult to compare the two. For example, in teachable agent studies, students typically do not realize natural discourse; instead, they tend to engage in very specific activities, such as completing graphical representations or answering multiple choice questions (e.g., Chin et al., 2010; Matsuda et al., 2013; Silvervarg et al., 2021). Another difference is that students who teach an agent typically receive quite some support, for instance in the form of adaptive metacognitive scaffolds or explicit feedback (e.g., Roscoe et al., 2013; Silvervarg et al., 2021; Tan et al., 2006). These differences make it difficult to compare these teaching situations to non-interactive teaching, where students engage in natural discourse and do not receive any support. Moreover, our inclusion criteria excluded almost all research on learning by generating a student product (e.g., websites, texts, videos for You-Tube)—with the exception of Hoogerheide et al., (2019b)—because this body of research tends not have an experimental design (i.e., no control condition; e.g., Orús et al., 2016), not include a teaching component (e.g., research on learning by making summaries for someone else; Fiorella & Mayer, 2016), and/or to allow students to generate the product in collaboration with other students which means there was an interaction component (e.g., Zahn et al., 2012, 2014).

The data search resulted in 236 hits (21 March 2020), from which 15 articles could be included, as they were thematically adequate (non-interactive teaching, experimental study), no duplicates, and primary English articles. Additionally, as recommended by Alexander (2020), we scanned the publication lists of prominent scholars (i.e., referential backtracking) who published journal articles about learning by non-interactive teaching for additional, relevant empirical work, which resulted in four additional articles. As a final safeguard, we also asked those scholars directly for potential gray literature (e.g., pre-prints) to provide an up-to-date overview of the current research literature on learning by non-interactive teaching. During the review process, we updated the literature with two articles on March 6, 2021. The entire procedure resulted in an inclusion of $n = 25$ articles (see Table 1 for an overview).

Based on the available literature, we first provide an overview of the central assumptions of why non-interactive teaching is assumed to promote students' learning. Second, we review what potential boundary conditions may constrain the effectiveness of non-interactive teaching. We then synthesize the available empirical evidence on processes and boundary conditions to provide a preliminary theoretical model of when and why non-interactive teaching is effective. Finally, we outline fruitful avenues for future empirical research and provide recommendations for educational practice.

What is Learning by (Non-Interactive) Teaching?

Learning-by-teaching involves situations in which students explain the previously learnt contents to another student to stimulate generative cognitive processes that may be conducive to learning. Seminal research on this *learning-by-teaching* activity primarily focused on teaching in *interactive settings*, such as during peer tutoring

or cooperative learning in classrooms or synchronous online learning environments (e.g., Annis, 1983; Bargh & Schul, 1980; Cohen et al., 1982). In interactive settings, learning-by-teaching is commonly characterized by three (recurring) core processes: studying learning materials in preparation for teaching, explaining the content of the learning materials to other students, and discussing the materials with other students (Bargh & Schul, 1980; Fiorella & Mayer, 2016; Renkl, 1995). The preparation phase and the interaction between the teaching students and their fellow students are both believed to make a valuable contribution to the effectiveness of learning-by-teaching (e.g., Duran, 2017; Kobayashi, 2021). For instance, studying learning materials with the explicit expectation of teaching the content later on has been shown to enhance learning outcomes relative to studying for a test (e.g., Fiorella & Mayer, 2013, 2014; see also section boundary conditions of non-interactive teaching). Additionally, during the interactions, for example, the fellow student may stimulate the teaching student's knowledge-building by pointing out inconsistencies, asking questions, and giving their own explanations (Plötzner et al., 1999; van der Veen et al., 2017; Webb et al., 1995).

However, recent research has shown that the learning-by-teaching effect also replicates in non-interactive settings (e.g., Fiorella & Mayer, 2013; Hoogerheide et al., 2014; Pi et al., 2021; Rittle-Johnson et al., 2008). *Learning by non-interactive teaching* entails studying learning materials and then teaching the material to an actual, remote, or imaginary audience, and lacks interaction with other students. Learning by non-interactive teaching can therefore be considered as providing a "monologous instructional explanation" (see Chi et al., 2017). This activity has become common practice for students across different age groups (Orús et al., 2016; Pimmer et al., 2019). Due to technological developments such as widespread internet access and access to recording devices (e.g., mobile phones, tablets) as well as easy-to-use communication platforms (e.g., Explain Everything, WhatsApp, YouTube, TikTok), many students nowadays not only watch but also record messages demonstrating their knowledge or skills in both educational and informal settings.

When used as an instructional activity, students are often explicitly told to adopt a teaching role by communicating distinct information on the subject matter to a fictitious fellow student with low levels of prior knowledge (e.g., Hoogerheide et al., 2014; Lachner et al., 2020). These explanations are typically oral explanations and recorded, although there are also non-interactive teaching studies in which students had to provide written explanations (e.g., Hoogerheide et al., 2016a; Jacob et al., 2020b; Lachner et al., 2021). An example of the specific instructions students commonly receive is provided by Fiorella and Mayer (2014):

> *"You will study a short lesson on how the Doppler Effect works and then be asked to teach the material that you learned. Specifically, you will be expected to provide a short (up to 5 minutes) video-recorded lecture explaining how the Doppler Effect works as if you were teaching the material to someone who has no prior knowledge of the subject." (p. 80).*

This example illustrates why non-interactive teaching is distinctly different from providing *self-explanations*, which entails instructing students to explain the subject matter to themselves (e.g., Bisra et al., 2018; Renkl & Eitel, 2019; Roy & Chi,

2005). That is, although explaining is key to both non-interactive teaching and self-explaining, self-explaining lacks the teaching component of instructing someone else. Moreover, there are other differences: For instance, self-explaining is often a concurrent activity during studying that is prompted to ensure high quality-explanations (e.g., Bisra et al., 2018; Fiorella et al., 2020; Rittle-Johnson & Loehr, 2017; Roscoe & Chi, 2008), whereas non-interactive teaching often happens after a full study phase and is not accompanied by additional instructional interventions such as prompts (see Bargh & Schul, 1980; Lachner et al., 2020).

Which Processes are Responsible for the Effectiveness of Learning by Non-Interactive Teaching?

There are three (not mutually exclusive) main views that aim to explain the beneficial effects of learning by non-interactive teaching: (1) retrieval practice, (2) generative processing, and (3) social presence (of an actual/implied/imagined audience). First, the *retrieval practice view* suggests that non-interactive teaching simply functions as a special case of retrieval practice, as a considerable amount of teaching time is dedicated to actively retrieving the information about the previously studied material from memory (Koh et al., 2018). Memory research has repeatedly shown that accessing information from long-term memory can strengthen the activated memory cues with a variety of learning materials, such as wordlists and complex conceptual materials (Carpenter, 2009; Roediger & Karpicke, 2006; Rowland, 2014). As such, explaining would mainly fulfill a consolidation function (see Waldeyer et al., 2020). Furthermore, research demonstrated that retrieval practice also supports students by helping them construct new retrieval cues (e.g., Carpenter, 2009; Endres & Renkl, 2015; Endres et al., 2017; Roediger & Butler, 2011; Rowland, 2014). From a cognitive perspective, retrieving information from memory supports the construction of new retrieval cues, likely because it helps students to activate the original and possibly also related information, thereby creating stronger retrieval traces that can more easily be activated (cf. elaborative retrieval hypothesis, Carpenter, 2009; Endres et al., 2017).

Second, according to the *generative processing view*, non-interactive teaching has benefits beyond retrieval practice, as explaining additionally triggers students' inference-making processes and may contribute to higher levels of generative processing as compared to retrieval practice (Fiorella & Mayer, 2016; Roscoe & Chi, 2008; cf. also cognitive elaboration perspective as described by Slavin, 1995). As such, non-interactive teaching may help students to actively process and make sense of the to-be-learned information (Renkl, 1995; Rittle-Johnson et al., 2008; Roscoe & Chi, 2008). Therefore, according to the generative view, students primarily learn from the cognitive and metacognitive learning processes that occur during the reconstruction of information. Cognitive processes that occur during generative activities, such as organization and elaboration processes, help students build a coherent mental representation of the subject-matter and integrate the new information with existing prior knowledge (Fiorella & Mayer, 2016; Kiewra, 2005; Wittrock, 1974). Metacognitive processes triggered by generative activities help students to evaluate their current

understanding and to apply adequate regulation strategies to repair gaps in under-standing (Fiorella & Mayer, 2016; Lachner et al., 2020). Given that students rarely engage in such generative processes spontaneously (see Berthold & Renkl, 2010; Nückles et al., 2020, for an overview), asking students to provide an explanation of the learning contents during non-interactive teaching may be conceived as a genera-tive strategy activator (see Fiorella & Mayer, 2016; Nückles et al., 2009; Reigeluth, 1983), which requires students to monitor their understanding due to an additional externalization of their knowledge, and subsequently re-organize and elaborate the contents in their explanations (Fiorella & Mayer, 2016; Lachner et al., 2018; Roscoe & Chi, 2008).

Third, a relatively novel perspective that has gotten distinct attention in recent research is the *social presence view* (Hoogerheide et al., 2016a, 2019a, b; Jacob et al., 2020a, 2021; Lachner et al., 2021). Social presence was originally defined as the extent to which people are aware of others in a technology-mediated setting and view those others as real (Short et al., 1976). More recently, following techno-logical advances, this definition was updated to "the psychological phenomenon in which, to a certain extent, the other persons are perceived as physical 'real' persons in technology-mediated communication enabled by computer-mediated communica-tion tools and electronic platforms" (Kreijns et al., 2021). The social presence view provides an extension of the generative processing view by arguing that the extent to which students engage in generative processing depends on the actual, implied, or imagined audience during teaching. Social presence effects are explained from three different perspectives. From a *discourse pragmatics perspective* (Lachner et al., 2021), it is assumed that students who engage in non-interactive teaching have a communication partner in mind to whom they direct their explanations during non-interactive teaching (Schober & Brennan, 2003), which might trigger distinct adap-tion processes (Clark & Brennan, 1991). For instance, students have to anticipate what the audience knows to adapt their teaching (Nickerson, 1999). These anticipa-tion processes may trigger specific audience-adjustments (cf. audience design; Rog-ers et al., 2013), and for instance lead students generate additional elaborations dur-ing their teaching to make the content more comprehensible for less-knowledgeable learners (see Wittwer et al., 2010, for empirical evidence). As such, non-interactive teaching is commonly assumed to contribute even more to students' learning than ego-centric generative activities such as self-explaining.

The *affective perspective* proposes a second pathway that feelings of social pres-ence also affect learning non-consciously via physiological arousal, which is a state of excitement or activation that causes an increase in heart rate, sweating, and blood pressure. It is well-established that both a real and an implied/imagined audience can elicit arousal and that the quality of task performance depends on people's physiological arousal levels, with a moderate degree of arousal being conducive to task performance compared to low and high levels of arousal (Aiello & Douthitt, 2001; Bond & Titus, 1983; Yerkes & Dodson, 1908). Regarding the effect arousal has on complex learning, there is research showing that relative to low and high lev-els of arousal, a moderate arousal level enhances various determinants of learning, such as memory consolidation, attention, and working memory capacity (Arnsten, 2009; Sharot & Phelps, 2004). Note that as a consequence, according to the affective

perspective, the relationship between social presence and learning is not so straightforward and might follow a reversed *U*-shaped curve.

Relatedly, from a *motivational perspective* (Hoogerheide et al., 2019b), non-interactive teaching might be a relatively engaging and enjoyable way to learn, because it is an active study approach that stimulates feelings of social connectedness with the (imagined/implied) audience (cf. relatedness, Deci & Ryan, 2012). As a result, learners might be motivated to do well and therefore invest more time and effort into learning relative to other study strategies that are more passive or do not have this audience component.

Evidence for and Against the Retrieval, Generative, and Social Presence View of Non-Interactive Teaching

To date, there is some empirical evidence for each view, but it is hard to gauge which of these three different accounts of the effects of non-interactive teaching is most likely valid, because most research did not explicitly or systematically test these different assumptions (see Table 1 for an overview). For instance, Koh et al. (2018) recently argued in favor of the retrieval view. In a lab experiment, Koh and colleagues compared the effects of non-interactive teaching to retrieval practice. After studying a multimedia lesson, students provided a video explanation without teaching notes (non-interactive-teaching-with-retrieval), recalled the information in written form (retrieval-only), or performed a filler task unrelated to the learning materials (control group). Another group of students additionally received a worked-out teaching script and was required to provide an explanation by reading the teaching script verbatim (non-interactive-teaching-without-retrieval). The authors found that students in the non-interactive-teaching-with-retrieval and the retrieval-only condition outperformed those who explained without retrieval and those in the control condition. However, there were no significant test performance differences between the non-interactive-teaching-with-retrieval and retrieval-only condition. Koh et al. (2018) interpreted the non-significant differences between the explaining and the retrieval condition in favor of the retrieval view. However, an important caveat of this study is that the non-interactive-teaching-without-retrieval condition simply read the teaching script aloud, which involved few if any generative or retrieval processes and might have led to a decrease in feelings of social presence. As such, the direct comparison between the retrieval and the non-retrieval condition has to be interpreted very cautiously.

Other recent studies showed initial evidence against the retrieval view and in favor of the generative view (see Table 1). For instance, Jacob et al. (2020a) and Lachner et al., (2020, Experiment 2) found that non-interactive teaching was more effective than a recall activity (see also Hoogerheide et al., 2014, Experiment 2; Hoogerheide et al., 2016a, Experiment 2). That said, in another study, Hoogerheide, Renkl, and colleagues (2019) found a teaching effect when students had access to the learning materials, which likely reduced the amount of active retrieval during non-interactive teaching. Further evidence in terms of the generative view comes from experimental studies which explicitly analyzed the characteristics that accounted

for the students' learning, suggesting that particularly generative activities, such as making elaborations mediated the effect of non-interactive teaching on students' learning (e.g., Fiorella & Kuhlmann, 2020; Lachner et al., 2018). Relatedly, several other studies found that non-interactive teaching improved students' monitoring accuracy (Fukaya, 2013; Jacob et al., 2020a), suggesting that non-interactive teaching not only fostered students' cognitive processing but also their metacognitive activities, as compared to retrieval practice. These findings suggest that, at the very least, the beneficial effects of non-interactive teaching cannot *only* be explained by the mere retrieval of information, although being able to successfully retrieve during teaching might be partly responsible for the non-interactive teaching effect (see Karpicke, 2017, for related evidence in the domain of retrieval practice). Relatedly, it must be noted that a large proportion of the studies only applied an immediate test, while retrieval activities might be most beneficial to learning after a delay (Fiorella & Mayer, 2016; Rowland, 2014). However, those studies that did include a delayed test demonstrated beneficial effects of non-interactive teaching both on an immediate posttest and a delayed posttest with similar effect sizes across both test moments (e.g., Fiorella & Mayer, 2014; Hoogerheide et al., 2014). Hence, it seems unlikely that test moment would be a boundary condition.

Referring to the discourse pragmatics perspective of social presence, Roscoe and Chi (2008) compared non-interactive teaching to interactive teaching (tutoring a peer which was present) and self-explaining, and as such varied the level of social presence, and associated anticipation processes. Surprisingly, the authors found that non-interactive teaching was less effective for learning than self-explaining or direct teaching. Analysis of the underlying cognitive and metacognitive processes during explaining revealed that self-explaining enhanced learning compared to non-interactive teaching because the self-explainers engaged more in knowledge-building processes and monitoring processes. Note that these results have to be interpreted with caution, because there were multiple differences between the non-interactive teaching and self-explaining condition that could have affected how much students learned. For instance, while the students who engaged in direct or non-interactive teaching provided their explanations after the study phase, the self-explainers were encouraged to continuously self-explain the content of the material while studying. These timing differences between conditions could have affected the findings (see Lachner et al., 2020).

Nevertheless, Lachner et al. (2021) found similar results while controlling for these potential confounding factors. They compared non-interactive teaching in written form (i.e., writing an explanation of the material to a fictitious peer) to writing self-explanations, and additionally included a written retrieval condition and a control condition (no study-relevant activity) as baseline. In a field-experiment, the self-explaining condition outperformed non-interactive teaching, retrieval, and the baseline condition. However, the authors did not replicate these results in a controlled laboratory setting. Neither self-explaining nor non-interactive teaching was more effective than retrieval or the control condition. The ineffectiveness of non-interactive teaching was possibly a result of the sample of students not having sufficient prior knowledge to benefit from non-interactive teaching (see also Wassenburg et al., 2020, Experiment 2, for related evidence on oral explaining).

Regarding the affective perspective of social presence, Hoogerheide and colleagues examined the role of arousal (Hoogerheide et al., 2019a, 2020a, b). Across three experiments, the authors could show that non-interactive teaching was associated with measures of physiological arousal by means of electro-dermal activity. Arousal did not account for students' learning outcomes in any of the experiments.

Finally, there is some initial evidence for a motivational social presence effect. In a field experiment by Hoogerheide et al., (2019a, 2019b), primary education students studied a text over the weekend and subsequently engaged in generating a summary for themselves (generative activity, no social component), creating a non-interactive teaching video (generative activity, social component), or restudying (control; no generative activity, no social component). After the weekend, children completed questionnaires and a knowledge test. The findings showed that non-interactive teaching improved test performance compared to restudy, while summarizing was not more effective than restudy. Moreover, teaching was more enjoyable than both summarizing and restudying, which mediated the effect of non-interactive teaching on test performance (see Jacob et al., 2021, for similar evidence in a controlled laboratory setting). One has to be cautious with interpreting these findings, however, as an alternative explanation for both the motivational and learning benefits of creating a non-interactive teaching video is that this was a more novel activity for the children than summarizing or restudying. The novelty effect proposes that when technologies are new, performance improves because the situational interest in the technology stimulates effort investment and persistence, yet performance quickly declines again as situational interest disappears (Clark, 1983).

In summary, the available empirical evidence suggests that non-interactive teaching is more than just a specific case of retrieval practice. There is evidence for a link between generative processing and learning as well as between social presence and learning (see Table 1). However, to which degree these two factors drive the (in-)effectiveness of non-interactive teaching is unclear. Most experiments were not designed to explicitly test the generative and social presence view, but rather investigated whether non-interactive teaching promotes learning or not relative to other common instructional strategies. The experiments that did explicitly test the underlying mechanisms by experimentally manipulating degrees of social presence during teaching (e.g., Hoogerheide et al., 2020b; Lachner et al., 2021) suggested that social presence during non-interactive teaching may be regarded as a double-edged sword, as high levels of social presence impaired rather than contributed to learning. There is some evidence to suggest that the motivational component of social presence accounted for the effectiveness of learning by non-interactive teaching, as increases of motivation could explain potential effects of non-interactive teaching (Hoogerheide et al., 2019b; Jacob et al., 2021).

Potential Boundary Conditions of Non-Interactive Teaching

Below, we provide an overview of potential boundary conditions of non-interactive teaching. Most of the studies on non-interactive teaching did not explicitly test for boundary conditions of non-interactive teaching. As such, the available evidence on

potential boundary conditions at the time of writing the theoretical review should be considered to be preliminary.

Modality: Spoken Versus Written Non-Interactive Teaching

Recent findings indicate that the modality of the non-interactive teaching activity matters. For example, Hoogerheide et al., (2016a) had students teach a fictitious fellow student aloud (on camera) or in writing. The content that they studied and taught was syllogistic reasoning. The authors found no direct differences between oral and written non-interactive teaching. However, whereas oral non-interactive teaching was more effective than restudy (see Table 1), written non-interactive teaching did not improve learning outcomes compared to restudy. In a related study with more complex materials (i.e., texts about combustion engines), Lachner et al. (2018) even found that oral non-interactive teaching enhanced learning more than written teaching (see also Jacob et al., 2020a).

These findings could be explained from a cognitive load perspective, as writing explanations may be more cognitively demanding and more time-consuming, because writing is a less automated process compared to speaking (see Cleland & Pickering, 2006; Sperling, 1996). However, with the exception of Hoogerheide et al., (2016a), none of the studies revealed differences between written and oral non-interactive teaching on measures of subjective cognitive load (Jacob et al., 2020a, 2021; Lachner et al., 2018). In line with the social presence view, social presence is discussed as an alternative theoretical account for why modality matters, as writing may trigger lower levels of social presence than speaking (Hoogerheide et al., 2016a; Jacob et al., 2020a). In several studies, it was found that students in the writing condition used fewer personal references (i.e., first and second personal pronouns) in their explanations than those in the oral condition, while there were no differences between the two teaching conditions regarding perceived difficulty or invested mental effort (see Hoogerheide et al., 2016a; Jacob et al., 2020a; Lachner et al., 2018). Personal references are commonly regarded as a coarse proxy of social presence in discourse pragmatics (see also Akinnaso, 1985; Chafe, 1982). Initial evidence suggested such a pathway via social presence, as Jacob et al. (2020a) documented that the effects of modality on learning outcomes could be explained by differences in personal references and the number of elaborated concepts. However, more validity studies which triangulate different methods are needed to clarify whether such a coarse proxy can be used to measure social presence, given that the relation between perceptions of social presence and the use of personal references is not fully clear (see Jacob et al., 2021, for mixed findings).

As an aside, a related issue is that researchers have used different types of recording of oral non-interactive explanations: audio (e.g., Jacob et al., 2020a; Lachner et al., 2018) or video (e.g., Fiorella & Mayer, 2013; Hoogerheide et al., 2019a, b; Lachner et al., 2020). Being aware that the non-verbal communication component is captured on video could increase perceptions of social presence (see Yoo & Alivi, 2001). However, the two studies that directly manipulated whether students provided

audio or video (oral) explanations showed no effects on learning outcomes (Waldeyer et al., 2020; Wassenburg et al., 2020).

Induced Social Presence by the Teaching Task

Another potential boundary condition is the level of perceived social presence induced by the teaching task. In line with the Yerkes-Dodson law (Yerkes & Dodson, 1908), the available evidence suggests that when the instruction of the teaching task affords high levels of social presence, non-interactive teaching loses its benefits and can even impair learning. Hoogerheide, Renkl, and colleagues (2020) found—across two separate experiments—that teaching the content of an example to another remote person via a webcam (a confederate who only listened; high social presence) *impaired* performance on an immediate and delayed problem-solving posttest relative to studying that example (no social presence), while teaching an example to a fictitious person (moderate social presence) did not impair (or improve) problem-solving performance relative to the study control condition. Explaining the example to a real person was particularly detrimental to performance on transfer tasks, suggesting that (too) high levels of social presence can impair students' understanding of the material. A recent study of Hoogerheide, Lachner, et al. (2020) also suggests that a high level of social presence is detrimental to the quality of students' cognitive schemata: Non-interactive teaching an example on video to four people (higher social presence) was as effective but a lot less efficient (i.e., resulted in similar test performance attained with a lot more mental effort) relative to explaining to one person (lower social presence). Note, however, that despite the fact that these experiments manipulated the core components of the social presence construct (i.e., degree of awareness/realness of audience), none of these experiments had an explicit measure of social presence, so there was no manipulation check, which warrants caution. Another study by Jacob et al. (2021) aimed at manipulating social presence through the teaching task—rather than the audience—by asking students to explain via a messenger chat including additional social cues, such as the recipients profile picture and a query message by the potential recipient (higher social presence) or to explain via a text editor without any social cues. The authors found that students in the messenger condition included more personal references, as potential behavioral proxy for social presence. These higher levels of social presence in the messenger condition, however, did not affect test performance relative to explaining in a text editor.

Timing of the Study Tasks

One study task-related boundary condition is the sequencing of the study and teaching tasks. Most research followed a study-teaching-test sequence in which students first studied the learning materials, taught the content of the study phase, and finally completed a posttest (e.g., Fiorella & Mayer, 2014; Fukaya, 2013; Hoogerheide et al., 2014, 2019a, b; Rhoads et al., 2019). The preference for teaching being the final task of the learning phase stems from the generative view, as non-interactive

teaching after a full study phase is believed to trigger students to create inferences about and elaborate on the contents, which should in turn result in deeper learning (Bargh & Schul, 1980; Renkl, 1995). Yet, there are reasons to believe that non-interactive teaching earlier in the learning phase (e.g., between study phases) is even more beneficial for learning than teaching late. Explaining early in the study phase could trigger students' metacognitive monitoring of their understanding, and help them become aware of potential knowledge deficits, which they can then try to resolve during further studying—provided that there is another study phase.

Across two experiments, Lachner et al. (2020) tested this assumption in the context of non-interactive teaching by having students teach between two study phases, in which they read two different passages of an expository text on combustion engines, or at the end, after reading both texts. A third group recalled the learning contents at the end of the study phase. The findings demonstrated no overall effect of teaching in comparison to retrieval. However, teaching between the study phase contributed to students' comprehension more than teaching after the study phase. Analyses of the generated explanations showed that the effect of early explaining was mediated by an increase in students' metacognitive monitoring.

Teaching Expectancy

A key question is whether or not studying with the expectancy of having to teach the learning materials to another person (without actually teaching) would already improve students' learning and help them make the most out of a later teaching activity (Fiorella & Mayer, 2016). Although this issue received quite some attention in non-interactive teaching research (e.g., Fiorella & Mayer, 2013; Hoogerheide et al., 2014) and in the early interactive teaching literature (e.g., Benware & Deci, 1984; Renkl, 1995; Ross & Di Vesta, 1976), research has yielded mixed findings. Several studies found that studying learning materials with a teaching expectancy improved learning outcomes relative to studying for a test (e.g., Fiorella & Mayer, 2013; Nestojko et al., 2014), while others found no differences (e.g., Hoogerheide et al., 2016a; Rhoads et al., 2019).

More importantly, there is some evidence that studying with a teaching expectancy can moderate the effectiveness of non-interactive teaching. Fiorella and Mayer (2014) allocated university students to one of four conditions following a 2 (study with test vs. teaching expectancy)×2 (non-interactive teaching vs. restudy) design. The authors found a moderation effect of teaching expectancy on learning by teaching: Students who made a video lesson performed better on a delayed comprehension test than those who restudied, and this non-interactive teaching effect was largest when preceded by a teaching expectancy than by a test expectancy. This moderation effect, however, could often not be replicated in other studies (e.g., Hoogerheide et al., 2014, 2016a; Rhoads et al., 2019; Wang et al., 2021), which is likely a result of the fact that the teaching expectancy effect is rather small (see Kobayashi, 2019) and that most studies did not have a large enough sample for reliably testing small (interaction) effects.

Inter-individual Effects of Prior Knowledge

Prior knowledge is a key moderating factor in research on learning and instruction (e.g., Kalyuga et al., 2003), and it is likely that students' knowledge prior to the teaching activity would also moderate the effect of non-interactive teaching on learning outcomes. As stated before, it is common for researchers to use a study-teaching-test sequence, presumably because teaching after a full study phase means that students have enough prior knowledge to generate high-quality explanations. The idea to maximize prior knowledge at the point of teaching is also in line with research on retrieval practice, as retrieval practice opportunities are most effective, if learners are able to successfully retrieve enough information of the learning materials (see Rowland, 2014). By contrast, students who have hardly any prior knowledge obviously cannot benefit from non-interactive teaching, as they would have little to explain.

The only empirical evidence on the importance of prior knowledge is provided by Hoogerheide et al., (2019a). They found that teaching the content of an example on how to troubleshoot electrical circuits improved problem-solving performance on retention (i.e., isomorphic) and transfer problems relative to studying that example. The effect on transfer was moderated by students' prior conceptual knowledge: Students who *initially* had low knowledge of the conceptual information required to understand the problem-solving task (e.g., the relationships among resistance, current, and voltage) profited more from non-interactive teaching than studying, while those with higher prior conceptual knowledge performed comparable regardless of experimental condition. It is possible that teaching helped students with lower conceptual knowledge to elaborate on the material and generate inferences, while this was not necessary for those who already had higher conceptual knowledge. These findings have to be interpreted with caution, however, as it is unclear what level of conceptual/procedural knowledge students had exactly prior to teaching (i.e., in-between the pretest and teaching, students were provided with two examples and a practice problem). Moreover, this moderation effect could not be replicated in other studies (e.g., Jacob et al., 2020b).

By contrast, there is also evidence that learners with too little conceptual prior knowledge do not benefit much from non-interactive teaching, as recent studies with rather low-prior knowledge learners found that non-interactive teaching was comparably or even less effective relative to simple learning strategies such as restudying the learning materials or free recall (Lachner et al., 2020, Experiment 1; Lachner et al., 2021; Wassenburg et al., 2020). The likely explanation is that in these studies, students did not have sufficient knowledge that would allow for the generation of elaborations and inferences during teaching.

Inter-individual Effects of Students' Ability Beliefs

Although non-interactive teaching research has predominantly focused on cognitive aspects of learning (i.e., learning outcomes and mental effort investment), there are reasons to believe that students' beliefs about their own abilities might be another critical boundary condition of instructional interventions (see Roelle & Renkl, 2020). Such ability beliefs are based on past experiences (e.g., self-concept, Marsh, 1990) and anticipated future experiences (e.g., self-efficacy, Bandura, 1989) and have been shown to be closely related to

learning gains (e.g., Caprara et al., 2008; Wäschle et al., 2014). A likely reason is that students with high ability beliefs have been shown to realize more deep-learning strategies. Apparently, students with high ability beliefs are more aware of their learning capabilities and therefore show greater persistence during learning activities, which eventually contributes to their achievement in a cyclical and reciprocal manner (Roelle & Renkl, 2020; Wäschle et al., 2014). In contrast, students with low ability beliefs may require additional help to initiate deep-learning strategies, such as by means of non-interactive teaching.

Investigating effects of academic self-concept, which is sometimes referred to as ability beliefs of past experiences, Jacob et al. (2020b) found that the non-interactive teaching effect was moderated by students' domain-specific self-concept. After a learning unit on photosynthesis, students were either engaged in non-interactive teaching (written/oral) or in restudy. The authors did not obtain a main effect of non-interactive teaching. However, additional moderation analyses revealed an interaction of self-concept and non-interactive teaching. Students with low levels of self-concept profited from non-interactive teaching as compared to restudy, while those with high self-concept did not. The authors attributed their findings to differences in perception of the social audience: Students with low self-concept profited more from non-interactive teaching, because it may have triggered a social situation of productive knowledge exchange, as both the audience and the "teacher" had comparable prerequisites. This perception might induce a situation of information sharing (see Ray et al., 2013), as both the producer and the recipient have high similarities (see Hoogerheide, van Wermeskerken, et al., 2016). Students with high self-concept, however, may no longer benefit from non-interactive teaching because they perceive to teach to a less capable peer. Such a situation may create a social situation implying downward comparisons, which have been shown to yield lower levels of information sharing (Ray et al., 2013), and likely lower learning gains. These interpretations, however, would have to be tested by future experimental research.

Characteristics of Learning Materials

Finally, the effectiveness of non-interactive teaching may depend on characteristics of the learning materials. For instance, there is initial evidence that the complexity of the learning materials matters. Jacob et al. (2020a) varied the linguistic complexity of texts and asked students to learn two texts, one of low complexity and one of high complexity, in a within-subjects design. Afterwards, students either retrieved or taught the contents of the texts. While teaching was more beneficial than retrieval for the high-complexity text, there were no differences among conditions with the low-complexity text. Low-complexity material in combination with tasks that require to retrieve the previously learnt contents might already sufficiently support students in constructing a coherent representation of the text (Berendes et al., 2018; McNamara, 2013), and make subsequent generative activities, such as non-interactive teaching obsolete. In contrast, high-complexity materials may require adding teaching activities to support students establish a coherent understanding of the text (see also Roelle & Nückles, 2019).

Next to material complexity, the nature of the materials might play a role. Non-interactive teaching research has mostly used conceptual materials (e.g., Fiorella &

Mayer, 2013, 2014; Hoogerheide et al., 2014). Recent studies examined whether the teaching effect would replicate with procedural materials, such as electronic troubleshooting tasks or inquiry tasks (Fiorella et al., 2017; Hoogerheide et al., 2019a, 2020a, b; Richter et al., 2020) or motor learning (Rhoads, 2019; Rhoads et al., 2019). Surprisingly, all these studies showed null effects, with the exception of Hoogerheide et al., (2019a), who found that teaching the content of an example improved problem-solving performance relative to studying that example. This effect, however, was qualified by an interaction with prior knowledge, as only low-prior knowledge students profited from teaching. In the same vein, three additional experiments with the same materials and similar student populations could not replicate this effect (Hoogerheide et al., 2020a, b). These findings may suggest that non-interactive teaching is not a beneficial instructional activity for procedural learning. However, we want to note that procedural learning tasks such as learning problem-solving skills from examples often also require considerable understanding about the underlying concepts (see Rittle-Johnson & Alibali, 1999), suggesting that the null findings found with procedural tasks were perhaps qualified by the type of problem-solving posttest test rather than the type of learning material.

A possible explanation for why non-interactive teaching may be particularly conducive to conceptual learning and less so to procedural learning, is that the cognitive processes stimulated by non-interactive teaching are better aligned with the processes required for conceptual learning than procedural learning. The aim of conceptual learning is to build up a rich conceptual network by acquiring distinct concepts as well as by relating these concepts to each other and to previously acquired conceptual information (i.e., prior knowledge) (Anderson, 1985; de Jong & Ferguson-Hessler, 1996). As learning by teaching entices students to explain potential why-questions of a fictitious peer, it allows for the generation of inferences and elaborations and could thereby help students integrate new concepts to their prior conceptual knowledge, and organize these concepts into a coherent representation (Fiorella et al., 2020; Lachner et al., 2018). Inferences and elaborations might not be as useful for procedural learning, because procedural learning requires students to acquire distinct rules and productions which are continuously automated and stored in procedural memory (e.g., Anderson, 1985). Self-explaining may have a similar function as non-interactive teaching regarding the support of conceptual understanding. However, in contrast to non-interactive teaching, self-explaining tasks are often accompanied by specific instructions to elicit the desired self-explanation processes (e.g., by comparing different examples and explaining the underlying rationale; see Rittle-Johnson & Loehr, 2017).
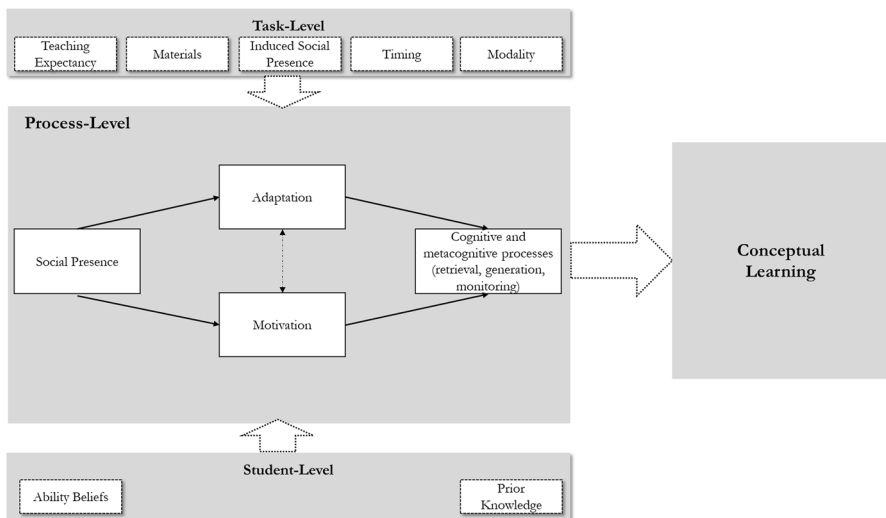
A Preliminary Model of Learning by Non-Interactive Teaching and Directions for Future Research

A synthesis of the available evidence on the underlying processes and the boundary conditions of learning by non-interactive teaching can be found in Fig. 1. Our model postulates that how much students learn from non-interactive teaching depends on

the design of the teaching task (i.e., task level), what students do/feel during the teaching task (i.e., process level), and who the students are (i.e., student level).

In the center, the synthesized model highlights the processes that are considered pivotal in determining the effectiveness of learning by non-interactive teaching. There is considerable evidence that students' learning depends on the extent to which they engage in cognitive processes such as generating elaborations and inferences as well as metacognitive processes such as comprehension monitoring (e.g., Fiorella & Kuhlmann, 2020; Lachner et al., 2018). Note that we view retrieving information from memory as one of these key generative processes (cf. Koh et al., 2018). Moreover, there is evidence that there is an important role for (processes triggered by) perceptions of social presence, and that the effects of social presence are mediated by motivational processes (Hoogerheide et al., 2019b; Jacob et al., 2021) and adaptation processes (Jacob et al., 2020a; Lachner et al., 2018). Motivation and adaption are assumed to influence learning outcomes via an adjustment in (meta) cognitive processes. Note that we did not include the affective perspective on social presence, because presently there is no evidence for a link between arousal and performance.

The top square of the model details the five task-related boundary conditions that have been found to influence the effectiveness of non-interactive teaching. Although there is only "initial" evidence for two of these factors (i.e., studying with a teaching expectancy and complexity/type of materials), there is considerable evidence that the non-interactive teaching task should not induce high levels of social presence, yet should instruct students to teach earlier on in the learning phase (rather than only at the end), and to speak the explanations aloud (rather than in written form). The bottom part of the model depicts potential effects of student-related boundary conditions. So far, there is initial evidence for the role of students' ability beliefs

Fig. 1 A preliminary model of learning by non-interactive teaching

(i.e., academic self-concept; Jacob et al., 2020b) and prior knowledge (Hoogerheide et al., 2019a). However, because these effects were only found in one study, they clearly require replication, ideally in studies which experimentally vary these inter-individual factors.

The literature reviewed in this article revealed important insights into when and why non-interactive teaching is conducive for learning. At the same time, as indicated by the preliminary model, our review identified crucial blind spots of this research field that open up important potential avenues for further research.

Research Agenda 1: Mechanisms of Non-Interactive Teaching

Our literature review highlighted the need to conduct more research explicitly targeted towards uncovering the potential mechanisms responsible for the effects of learning by non-interactive teaching, as most of the studies were not designed to test and compare the different mechanisms. Hence, we would argue that future research should experimentally disentangle the potential effects of retrieval, generation, and perceptions of social presence. A fruitful approach for instance could be to cross different factors such as the availability of learning materials (open- versus closed-book) to manipulate the amount of retrieval activities during non-interactive teaching (see Hiller et al., 2020, for related approaches on self-explaining), and the social presence during the teaching tasks, for instance by manipulating the presence of a student (e.g., Hoogerheide et al., 2020b; Lachner et al., 2021).

Any such examinations should preferably include (multiple) process measures. Recent studies did start to include process measures, such as arousal (Hoogerheide et al., 2019a; Pi et al., 2021), motivation (Hoogerheide, et al., 2019b; Jacob et al., 2021), or adaption processes (Fiorella & Kuhlmann, 2020; Jacob et al., 2020a; Lachner et al., 2020). However, most studies only included a single process measure, making it difficult to compare the relative relevance and the interplay of different mechanisms. Relatedly, only two studies attempted to measure perceptions of social presence (Jacob et al., 2021; van Brussel et al., 2020). Therefore, a potential goal for future research could be to triangulate these measures to provide integrated answers to which mechanisms account for the effects of learning by non-interactive teaching and how these mechanisms relate to one another.

Research Agenda 2: Individual Differences in the Effectiveness of Non-Interactive Teaching

Our review and model highlight that there is a paucity of research examining the potential importance of individual differences, with the exception of ability beliefs and prior knowledge, which received some attention but require replication to be considered as robust moderators. Hence, we stress the importance of uncovering other potential characteristics that could determine the effectiveness of non-interactive teaching.

For instance, following research on teacher expertise (Borko & Livingston, 1989; Lachner et al., 2016; Leinhardt & Greeno, 1986), teaching experience could be such a

moderating factor (see Herppich et al., 2014, for empirical evidence in the context of tutoring). Teaching experience could cause students to have more accurate beliefs about what constitutes effective explanations during teaching, to be better at monitoring whether explanations are comprehensible for the audience, and to experience fewer negative emotions during teaching (e.g., worrying thoughts) which might allow more working memory resources to be dedicated to the activity of teaching. Relatedly, from a motivational perspective, the role of teaching efficacy may deserve further attention, as the beliefs about one's own competence to realize distinct teaching tasks have been shown to considerably affect the quality of teaching (see Klassen & Tze, 2014, for an overview). From a methodological perspective, in addition to moderation analyses, an alternative approach would be to experimentally manipulate these characteristics (see Fyfe & Rittle-Johnson, 2016; Wolff et al., 2018, for empirical examples). Such approaches would allow for drawing causal conclusions regarding the effects of student-related boundary conditions.

Research Agenda 3: Enhancing the Effectiveness of Non-Interactive Teaching

Related to the issue of uncovering for which learners and when non-interactive teaching works best, we want to emphasize the need of investigating how to further enhance the effectiveness of non-interactive teaching. This question is crucial for educational practitioners who (want to) utilize this strategy in practice. One fruitful way might be to examine how to best sequence non-interactive teaching in relation to or in combination with other effective instructional activities, because the effects of non-interactive teaching were mainly examined "in isolation" (for an exception, see Fiorella & Kuhlmann, 2020). Based on the moderating role of prior knowledge, it seems sensible to expect that learning by teaching is particularly suited for advanced (i.e., later) phases of knowledge acquisition, to enable students to provide high-quality explanations (see Lachner et al., 2021, for related discussions). Other generative strategies such as drawing that directly support the construction of knowledge (rather than mainly have a consolidation function) might be more suited for earlier phases of knowledge acquisition (see also Fiorella & Kuhlmann, 2020; Fiorella & Mayer, 2016, for related discussions).

Another approach is to examine the effects of providing instructional support during the teaching activity. To date, only one study examined the effects of providing such support (Lachner & Neuburg, 2019). In this study, the authors demonstrated that the addition of formative feedback during non-interactive teaching enhanced the quality of the generated explanation, which yielded deeper comprehension. Further inspiration could be drawn from the rich body of research on enhancing the effectiveness of self-explaining or writing interventions (Bisra et al., 2018; Klein et al., 2018). For instance, regarding self-explaining, it is well-documented that focused prompting (e.g., Johnson & Mayer, 2010; Renkl & Eitel, 2019; Rittle-Johnson & Loehr, 2017) or even explicit training (e.g., Kurby et al., 2012) helps students make better self-explanations and thereby learn more. It seems sensible to assume that these strategies also work for non-interactive teaching. Additionally, research in the field of teacher education may provide further useful insights into how explaining skills can be enhanced (Findeisen et al., 2020; Weinhuber et al., 2019), for instance

by video-based interventions to make non-interactive teaching more effective. Such interventions could not only comprise strategies of generating high-quality explanations, but also help students' monitoring whether their explanations are comprehensible for their audience.

Research Agenda 4: Bringing Non-interactive Teaching Into the Wild

A further caveat of previous research is that because most empirical studies were conducted in the laboratory (see Hoogerheide et al., 2019b; Jacob et al., 2020b; Lachner et al., 2021, for exceptions), it is largely unclear whether findings transfer to educational practice. It is possible that non-interactive teaching would become more effective in applied settings. All the studies included in our review used a "stripped down" version of non-interactive teaching by limiting which activities students could engage in and for how long. Often, students were given a limited amount of time to prepare their teaching, not allowed to take notes, or not informed at all before the study phase that they would have to teach the learning materials. Moreover, students were never allowed to revise their oral teaching scripts or to redo the teaching activity (see Lachner & Neuburg, 2019, for exceptions on written teaching). It is likely that in applied settings when students are in control of their learning, they would make different choices (e.g., prepare longer, generate a teaching script, restudy parts of the learning materials, engage in repeated teaching), which could enhance how much they learn. Moreover, as many studies only included an immediate posttest (see Fiorella & Mayer, 2014; Hoogerheide et al., 2014, for exceptions), future research should include more delayed measurements to examine whether any effects remain stable after a delay. Ideally, the effects of non-interactive teaching would be examined in an applied setting and over time, for instance as part of a multi-week course. Such designs would allow to test whether findings of non-interactive teaching may arouse by the activity itself or, for example, simply because of a kind of novelty effect (Clark, 1983).

A final limitation of the previous studies refers to the fact that most studies were conducted with learning materials from the STEM domain, which often rely heavily on visuo-spatial processing (e.g., Doppler effect, respiratory system, motor engine). As such, it is unclear whether the findings on learning by non-interactive teaching would replicate with learning materials from different domains (e.g., liberal arts). Similarly, the vast majority of studies used self-study materials (e.g., expository texts, multimedia material), so it is unclear whether the findings would hold in more complex learning scenarios such as actual teaching.

Conclusions

Despite the increased interest from researchers and practitioners in learning by non-interactive teaching in recent years, our knowledge of when and why non-interactive teaching promotes learning was still limited. In this review, we have taken a step

toward filling this knowledge gap by reviewing the available literature on processes and potential boundary conditions of non-interactive teaching which we synthesized into a to-be-updated model. We hope that this review successfully delineated a research agenda that can help transition this relatively young but promising field of research from investigating whether non-interactive teaching is an effective instructional activity to why and under which conditions non-interactive teaching promotes learning and how its effectiveness could be further improved. Given that research on non-interactive teaching is relatively recent, a large proportion of included studies was gray literature (i.e., non-published studies), which at the time of writing this review had not been peer-reviewed yet. On the one hand, one may argue that there is a chance that these papers could be of a somewhat "lower quality" due to lower levels of quality control. On the other hand, including gray literature may also help reduce publication bias and increase the comprehensiveness and timeliness of the review.

We also hope that this review will help teachers who (want to) utilize non-interactive teaching in their classes or as homework assignments to ensure that their implementation of this activity is as effective as possible. Based on the limited available evidence, it seems advisable to use non-interactive teaching as an activity when students have to acquire complex conceptual knowledge from expository texts or multimedia material. It seems less useful when students have to acquire more basic conceptual knowledge or procedural knowledge (although it does not hurt learning in this case, the lack of significant gains should be weighed against the higher effort this activity requires from students). Moreover, it seems best to let students (1) explain aloud (rather than in writing), (2) explain from memory (rather than with the materials available to them), (3) study the materials with a teaching expectancy prior to the non-interactive teaching activity, and (4) restudy the materials again after teaching (rather than placing the non-interactive teaching activity at the end). However, given that research has mostly focused on the question of whether this activity works or not, more research is needed to determine under which conditions non-interactive teaching works best, and it is important that future research explicitly tests these boundary conditions.

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