Learning by Teaching: The Effects of Learner-Generated Teaching on Learning

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Abstract

Learning by non-interactive teaching refers to learners switching roles during the knowledge acquisition process and explaining what they have learned to others in the capacity of a knowledge transmitter. The retrieval practice hypothesis, generative learning hypothesis, and social presence hypothesis respectively explain the positive effects of this approach on learners from the perspectives of memory consolidation, generative cognitive processing, and social presence. Summarizing relevant research findings reveals that different implementation methods of learning by non-interactive teaching produce varying effects on learning promotion. Specifically, implementing this approach in oral form with a teacher' s image (e.g., video) can effectively improve learners' immediate comprehension, immediate transfer, delayed comprehension, and delayed transfer performance compared to simple learning tasks such as restudying and retrieval practice, and may represent a superior implementation method. In contrast, implementing this approach in oral form without a teacher' s image (e.g., voice-only) or in written form (e.g., text) exerts relatively weak positive effects on learning outcomes. The cognitive theory of multimedia learning may provide supplementary explanations for the differences in promotional effects among these various implementation methods. Learners engaged in learning by non-interactive teaching may also experience heightened motivation and enjoyment and demonstrate willingness to invest greater mental effort during the teaching process. Future research should further investigate aspects such as theory testing and integration, determination of boundary conditions, and optimization of learning by non-interactive teaching.

Full Text

Learning by Non-Interactive Teaching: The Impact of Learner-Generated Teaching on Learning

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Abstract: Learning by non-interactive teaching refers to a learning strategy where learners switch roles during knowledge acquisition, explaining what they have learned to others as if they were instructors. The retrieval practice hypothesis, generative learning hypothesis, and social presence hypothesis each explain the positive effects of learner-generated teaching from the perspectives of memory consolidation, generative cognitive processing, and social presence, respectively. A review of relevant studies reveals that different implementations of self-generated teaching produce varying effects on learning. Specifically, oral forms with an instructor presence (e.g., video) significantly improve learners' immediate comprehension, immediate transfer, delayed comprehension, and delayed transfer performance compared to simple learning tasks such as restudying or retrieval practice, suggesting this may be an optimal implementation method. In contrast, oral forms without an instructor presence (e.g., audio only) or written forms (e.g., text) show only weak positive effects on learning outcomes. The Cognitive Theory of Multimedia Learning may provide supplementary explanations for these differences in effectiveness across implementation methods. Learners engaged in self-generated teaching also experience higher motivation and enjoyment and are willing to invest more mental effort. Future research should examine and integrate theoretical frameworks, identify boundary conditions, and optimize self-generated teaching strategies.

Keywords: learning by non-interactive teaching, generative learning, social presence, retrieval practice, metacognitive processing

> "Thus, after learning one knows one' s inadequacy; after teaching one knows one' s difficulty. Knowing inadequacy leads to self-reflection; knowing difficulty leads to self-strengthening. Therefore it is said: 'Teaching and learning promote each other.' " —*The Book of Rites: Record of Learning*

In traditional face-to-face classrooms and online video learning, students primarily receive knowledge passively. With the increasing popularity of online learning, students now watch videos on desktop computers or mobile devices (phones or tablets) more frequently than ever. However, this learning approach has proven less than ideal (Reich & Ruipérez-Valiente, 2019), likely because passive viewing weakens "student-centered" active participation, making it difficult even for well-designed videos to prompt appropriate cognitive processing and deep understanding (Fiorella et al., 2020). Meaningful learning and durable

knowledge retention require students to actively generate and construct knowledge during the learning process (Fiorella & Mayer, 2016). Chinese culture has long emphasized "teaching and learning promote each other" in the interaction between instruction and learning, highlighting how role changes and different perspectives contribute to knowledge construction. Educational psychologist John Dewey' s concept of "learning by doing" also suggests that students should learn through activity— "understanding while doing" —where active observation, experimentation, and inquiry facilitate knowledge construction and meaningful learning (Dewey, 2012). However, not all activities guarantee that students will "learn" from "doing" ; activity design should be closely connected to the learning content. "Learning by teaching" refers to learning through explaining material to others, where the teaching activity can be integrated with the content, focusing students' attention on analyzing and elaborating the material to promote learning (Fiorella & Mayer, 2015).

Early research predominantly explored the positive effects of "learning by teaching" through peer tutoring, cooperative learning, and group discussions (e.g., Roscoe, 2014; Roscoe & Chi, 2008; Slavin, 1983; Webb, 1982). Fiorella and Mayer (2016) synthesized these studies and found that "learning by teaching" produced a median effect size of $d = 0.77$, making it a highly effective generative learning activity. However, because "learning by teaching" involves numerous factors and varied implementation approaches, it is also a relatively complex learning activity.

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To better understand and apply "learning by teaching," researchers have attempted to systematically isolate the effects of its three subcomponents: preparing to teach, explaining to others, and interacting with others. For example, Fiorella and Mayer (2013) informed participants they would teach another learner about the Doppler effect, provided them with text materials on the topic, asked them to study the content, and then had them explain the material to an imagined, absent learner (by recording a teaching video, as shown in Figure 1 [Figure 1: see original paper]) to examine how preparing to teach and explaining to others promote learning when interaction is removed. The results showed that even without interaction with others, students who learned through teaching demonstrated significantly better conceptual knowledge acquisition than those who simply restudied the material.

Figure 1. Example of learner self-generated teaching

To distinguish "learning by teaching" that does not involve interaction with others, this paper adopts the term "self-generated teaching" to refer to "learning by teaching without audience presence or interaction" —that is, learning through non-interactive teaching (e.g., recording instructional videos). With

the rapid development of information technology and online learning environments, recording and sharing videos has become simple and engaging for students, and creating instructional videos does not require others' participation, facilitating autonomous remote learning. Consequently, learner self-generated teaching has recently attracted widespread attention from educational psychology researchers both domestically and internationally (Fiorella & Mayer, 2013, 2014; Hoogerheide et al., 2018, 2019).

This paper synthesizes 28 experimental studies (see Table 1) to systematically review and objectively evaluate the positive effects of this learning activity, aiming to provide direct reference for researchers and readers. First, we categorize and introduce how recent studies have implemented self-generated teaching. Second, we address the primary concern of educators and researchers: whether self-generated teaching can improve learning outcomes. We summarize and analyze this from two perspectives—overall effects and effects of different implementation methods. Third, we examine whether self-generated teaching influences learning experience and thus affects learning, specifically exploring its impact on cognitive load, motivation, and enjoyment across different implementations to partially explain its effects on learning outcomes. Fourth, we discuss the theoretical mechanisms underlying the effectiveness of self-generated teaching, attempting to validate existing theories while supplementing them with the Cognitive Theory of Multimedia Learning to further explain differences in effectiveness across implementation methods. Finally, we summarize and discuss these findings.

1. How Is Learner Self-Generated Teaching Implemented?

Learner self-generated teaching refers to a strategy where learners switch roles during knowledge acquisition, explaining what they have learned to other learners from an instructor' s perspective, aiming to help learners actively participate in knowledge construction (Fiorella & Mayer, 2022; Lachner et al., 2022). Numerous empirical studies have shown that learner self-generated teaching can significantly enhance learners'memory and understanding of knowledge (Fiorella & Kuhlmann, 2020; Hoogerheide et al., 2016, 2018, 2019; Lachner et al., 2020, Exp2; Lim et al., 2021; Pi et al., 2020; Wang et al., 2021). However, many researchers have also failed to find positive effects of self-generated teaching on learning (Hoogerheide et al., 2016, Exp1; Jacob et al., 2020, 2021, 2022; Koh et al., 2018; Lachner et al., 2021; Okita et al., 2013, Exp1; van Brussel et al., 2021).

Considering the substantial variation in implementation methods, learner self-generated teaching can be categorized into three main types: oral forms with an instructor presence (e.g., recording teaching videos via camera or device webcams, face-to-face teaching without interaction), oral forms without an instructor presence (e.g., recording only audio via microphone), and written forms without an instructor presence (e.g., writing teaching texts on paper or in computer text boxes/chat windows). These different implementations (video, audio,

or text) may lead to varying effects on learning. For instance, Hoogerheide et al. (2016) used syllogistic reasoning as learning material to compare video and written forms of self-generated teaching, finding that video-based self-generated teaching significantly improved learning outcomes compared to a recall task, while written forms showed no such benefit. Lachner et al. (2017) used knowledge about internal combustion engine structure and function to compare audio and written forms, finding that audio was more effective than written forms (similar results in Jacob et al., 2020). Additionally, Lachner et al. (2020) found that video-based self-generated teaching significantly outperformed retrieval practice (similar results in Hoogerheide et al., 2016), whereas Jacob et al. (2021) failed to find that audio-based self-generated teaching promoted learning more than retrieval practice (similar results in Jacob et al., 2022). Different implementations of self-generated teaching may create varying levels of social presence, leading to differences in cognitive processing quality and thus affecting explanation quality and learning outcomes (Hoogerheide et al., 2016; Jacob et al., 2020). However, these speculations based on limited empirical studies require more quantitative and systematic review for further verification.

To more clearly reflect the impact of learner self-generated teaching on learning, this paper primarily analyzes its effects on learning outcomes, examining both overall effects and categorized effects of different implementation methods (see Table 1), then explains these effects through learning experience and theoretical hypotheses.

2. Can Learner Self-Generated Teaching Improve Learning Outcomes?

Many empirical studies have shown that self-generated teaching is an effective learning strategy, where learners explaining material to imagined peers through video, audio, or text can effectively improve their own learning outcomes (e.g., Fiorella & Kuhlmann, 2020; Fiorella & Mayer, 2013, 2014, 2016; Hoogerheide et al., 2014, 2016, 2018, 2019; Jacob et al., 2020; Koh et al., 2018; Lachner et al., 2020; Lim et al., 2021; Pi et al., 2020; Wang et al., 2021). For example, Hoogerheide et al. (2014) used syllogistic reasoning as learning material and found that learners who self-generated teaching through video recording showed higher performance on immediate and delayed comprehension and transfer tests compared to those who restudied. Jacob et al. (2020) used complex immunology knowledge and found that audio-based self-generated teaching produced higher immediate transfer scores than retrieval practice (recalling content). Lim et al. (2021) used Doppler effect knowledge and found that writing verbatim teaching scripts as self-generated teaching improved delayed transfer performance. Some researchers, however, have not found positive effects (e.g., Hoogerheide et al., 2016, Exp1; Jacob et al., 2021, 2022; Lachner et al., 2020, Exp1; van Brussel et al., 2021). For instance, Koh et al. (2018) found that video-based self-generated teaching did not improve delayed comprehension compared to retrieval practice. Jacob et al. (2021) used immunology knowledge and found

no benefit of audio-based self-generated teaching. Lachner et al. (2021) used endocarditis knowledge and found no positive effect of written self-generated teaching.

To more intuitively present the empirical research on self-generated teaching' s impact on learning outcomes, following previous formats (Mayer, 2021), this paper compiled effect sizes (Cohen' s d) from these studies and calculated median effect sizes (see Table 1) to provide a directional answer and reference for future researchers. The median effect size refers to the median of effect sizes (calculating effect sizes for a dependent variable across independent studies, then finding the median of these effect sizes), a method increasingly used in multimedia learning reviews and monographs to effectively explain and reflect the current state of research (e.g., Kuang et al., 2022; Fiorella & Mayer, 2016; Mayer, 2021). Included studies met the following criteria: (1) must compare self-generated teaching with simple learning strategies (single study, restudying, free recall, fill-in-the-blank tasks, retrieval practice); (2) learning content must be meaningful and logically structured; (3) dependent variables must include learning outcomes or learning experience. After screening, 22 articles comprising 28 studies were included in the analysis (see Table 1).

Comprehension tests generally assess shallow processing such as knowledge recall and retrieval (Mayer, 2021). Table 1 summarizes 41 comparisons between self-generated teaching and simple learning methods (e.g., restudying, recall tasks, retrieval practice). Among these, 30 examined immediate comprehension tests (administered immediately after learning), with a median effect size of d = 0.11 for self-generated teaching. (1) For oral forms with instructor presence (e.g., video, face-to-face, imagination), 16 comparisons found that 10 (63%) promoted immediate comprehension while 6 (37%) showed no effect, yielding a median effect size of $d = 0.56$. (2) For oral forms without instructor presence (e.g., audio only), 4 comparisons found no effect (100%) on immediate comprehension, with a median effect size of $d = 0.09$. (3) For written forms without instructor presence (e.g., text), 11 comparisons found no effect (100%) on immediate comprehension, with a median effect size of d = -0.16. Fifteen comparisons examined delayed comprehension tests (administered one week later), with a median effect size of $d = 0.57$ for self-generated teaching overall. (1) Oral forms with instructor presence accounted for 13 comparisons, with 10 (77%) promoting delayed comprehension and 3 (23%) showing no effect, yielding a median effect size of $d = 0.63$. (2) No comparisons examined oral forms without instructor presence. (3) Written forms without instructor presence accounted for 2 comparisons, with 1 (50%) promoting delayed comprehension and 1 (50%) showing no effect, yielding a median effect size of $d = 0.39$.

Transfer tests assess deep processing such as knowledge extension and application (Mayer, 2021). Among the 41 comparisons in Table 1, 26 examined immediate transfer tests, with a median effect size of $d = 0.21$ for self-generated teaching. (1) Oral forms with instructor presence accounted for 12 comparisons, with 5 (42%) promoting immediate transfer and 7 (58%) showing no effect, yield-

ing a median effect size of $d = 0.35$. (2) Oral forms without instructor presence accounted for 4 comparisons, with 1 (25%) promoting immediate transfer and 3 (75%) showing no effect, yielding a median effect size of $d = 0.02$. (3) Written forms without instructor presence accounted for 11 comparisons, with 1 (9%) promoting immediate transfer and 10 (91%) showing no effect, yielding a median effect size of $d = 0.08$. Six comparisons examined delayed transfer tests, with a median effect size of $d = 0.69$ for self-generated teaching. (1) Oral forms with instructor presence accounted for 5 comparisons, with 4 (80%) promoting delayed transfer and 1 (20%) showing no effect, yielding a median effect size of $d = 0.76$. (2) No comparisons examined oral forms without instructor presence. (3) Written forms without instructor presence accounted for 1 comparison, which found no effect (100%) on delayed transfer, with an effect size of $d = 0.19$.

In summary, different implementations of self-generated teaching show considerable heterogeneity in their effects on learning outcomes. Compared to oral or written forms without instructor presence, oral forms with instructor presence (e.g., recording teaching videos, face-to-face teaching, imagination) effectively promote learning and represent a more ideal implementation. First, this may be because recording teaching videos creates a more effective teaching context than writing teaching texts, eliciting higher social presence. Specifically, video recording better facilitates learners' shift to a "teacher" perspective, prompting them to invest more cognitive processing in "helping the audience learn." Consequently, they continuously adjust and optimize their explanations to generate accurate, complete, and appropriate information for the audience, which actually enhances their own understanding of the material (e.g., generating more personal pronouns and detailed elaborations of key concepts, see Jacob et al., 2020; Lachner et al., 2022). Moreover, higher social presence may also stimulate greater motivation (incentivizing learners to invest more mental effort to initiate and maintain appropriate and sufficient cognitive processing, Fiorella & Mayer, 2016; Hoogerheide et al., 2016) and moderate arousal (enhancing working memory and memory consolidation, Hoogerheide et al., 2018; Roozendaal, 2002), further positively influencing learning. Second, recording teaching videos (or audio, spoken language) is a more automatic and less cognitively demanding activity than writing teaching texts (written language), which may allow learners to allocate more cognitive resources to necessary and deep processing of the learning material itself (Hoogerheide et al., 2016; Lachner et al., 2022). Finally, audio-only forms (without camera) may create a weaker teaching context than video forms (with camera gaze), insufficient to help learners successfully adopt the "teacher" perspective and eliciting lower social presence, motivation, and arousal, thus showing minimal learning benefits (e.g., Jacob et al., 2021, 2022).

3. Can Learner Self-Generated Teaching Affect Learning Experience?

Researchers have also examined self-generated teaching' s impact on learning experience (cognitive load or mental effort, motivation, enjoyment) to partially

explain its effects on learning outcomes. Among the 41 comparisons in Table 1, 22 examined cognitive load, with a median effect size of $d = 0.45$ for self-generated teaching. (1) Oral forms with instructor presence accounted for 10 comparisons, with 4 (40%) increasing cognitive load and 6 (60%) showing no effect, yielding a median effect size of $d = 0.47$. (2) Oral forms without instructor presence accounted for 3 comparisons, with 2 (67%) increasing cognitive load and 1 (33%) showing no effect, yielding a median effect size of $d = 0.61$. (3) Written forms without instructor presence accounted for 9 comparisons, with 4 (44%) increasing cognitive load and 5 (56%) showing no effect, yielding a median effect size of $d = 0.37$.

Overall, self-generated teaching may increase learners' cognitive load. On one hand, higher cognitive load may indicate that learners invest more mental effort during teaching. Specifically, video or audio forms better facilitate learners' shift to a "teacher" perspective, strengthening their willingness to "help others learn," which may lead them to invest more mental effort in selecting, organizing, integrating, elaborating, and monitoring learning materials, ultimately resulting in better performance (e.g., Hoogerheide et al., 2016, 2018, 2019; Jacob et al., 2020; Pi et al., 2020). We consider this increased cognitive load beneficial, also known as germane cognitive load. On the other hand, written teaching (written language) is a non-automatic and more complex process than oral forms (spoken language), potentially causing learners to engage in excessive extraneous processing that negatively impacts learning (e.g., Hoogerheide et al., 2016; Jacob et al., 2021). We consider this increased cognitive load detrimental, also known as extraneous cognitive load. However, previous studies measuring subjective cognitive load have not distinguished between these types (e.g., Lachner et al., 2017), making it impossible to determine whether increased cognitive load is beneficial or harmful. Future research should address this limitation.

A few researchers have examined self-generated teaching' s effects on motivation and enjoyment. Among the 41 comparisons in Table 1, 2 examined motivation and 5 examined enjoyment. Analysis revealed that compared to restudying or retrieval practice, self-generated teaching learners experienced higher motivation (median effect size: $d = 0.44$) and enjoyment (median effect size: $d = 0.76$), though relevant empirical studies remain limited, and the role of motivation and enjoyment in promoting learning is unclear (Hoogerheide et al., 2019; Jacob et al., 2021; Pi et al., 2020; Wang et al., 2021). Specifically, Pi et al. (2020) and Wang et al. (2021) both found that self-generated teaching learners had higher motivation and better learning performance compared to restudying. Hoogerheide et al. (2019) also found that self-generated teaching learners reported higher enjoyment and better learning performance than those generating summaries or restudying, with enjoyment mediating the relationship between learning activity and performance. However, Jacob et al. (2021) found that although self-generated teaching learners had higher enjoyment than retrieval practice learners, they did not achieve better learning outcomes.

Overall, positive experiences during teaching may promote learning. Future re-

search should continue to examine whether motivation and enjoyment directly or indirectly facilitate learning by influencing cognitive processing, or both. Moreover, whether motivation and enjoyment are triggered by the self-generated teaching strategy itself or merely by its novelty also requires further investigation.

Table 1. Summary of Effect Sizes (Cohen' s *d*) from Empirical Studies on Learner Self-Generated Teaching

Study	Sample Size	Sample Age	Experimental Manipulation	Effect Sizes
Fiorella & Kuhlmann, 2020			Teaching vs. restudying (human respiratory system)	Cd(0.46), Td*(0.76)
Fiorella & Mayer, 2013, Exp1			Teaching with drawing vs. restudying (human respiratory system)	Cd*(1.15),* *Td*(1.34)
Fiorella & Mayer, 2013, Exp2			Doppler effect: teaching vs. no activity	Ci*(0.82)
Fiorella & Mayer, 2014, Exp2			Doppler effect: teaching vs. no activity	Cd*(0.79)
Fukaya, 2013, Exp1			Doppler effect: teaching vs. restudying	Cd*(0.90)
Fukaya, 2013, Exp2			Daily device operation: face-to-face teaching vs. generating keywords	Ci(0.27), Ti(0.70)
Hoogerheide et al., 2014, Exp1			Syllogistic reasoning: teaching vs. restudying	Ci(0.52), Ti*(0.74);* *Cd(0.43),* *Td*(0.62)
Hoogerheide et al., 2014, Exp2			Syllogistic reasoning: teaching vs. restudying	Ci*(0.88),* *Ti*(0.35); Cd*(0.96),* *Td*(0.85)

Study	Sample Size	Sample Age	Experimental Manipulation	Effect Sizes
Hoogerheide et al., 2016, Exp1			Syllogistic reasoning: teaching vs. restudying (written on paper)	Ci(0.04), Ti(0.28)
Hoogerheide et al., 2016, Exp2			Syllogistic reasoning: teaching vs. restudying (written in text box)	Ci(0.39), Ti(0.31); Cd(0.12), Td(0.19)
Hoogerheide et al., 2018			Circuit troubleshooting: teaching vs. recall task	Ci*(0.63),* *Ti(0.14);* *Cd*(0.57), Td(-0.02)
Hoogerheide et al., 2019			Sexual and asexual reproduction: teaching vs. restudying	Ci*(1.13),* *Ti*(1.63)
Jacob et al., 2020			Sexual and asexual reproduction: teaching vs. retrieval practice	Cd*(0.71)
Jacob et al., 2021			Immunology: teaching vs. retrieval practice	Ci(0.11), Ti(-0.20)
Jacob et al., 2022			Immunology: teaching vs. retrieval practice	Ci(-0.08), Ti*(0.52)
Kobayashi, 2021			Written (text box): teaching vs. retrieval practice	Ci(-0.16), Ti(-0.46)
Koh et al., 2018			Written (text box): teaching vs. retrieval practice	Ci(-0.22), Ti*(0.20)
Lachner et al., 2020, Exp1			Four-stroke engine: teaching vs. retrieval practice	Ci(0.06), Ti(-0.04)
Lachner et al., 2020, Exp2			Four-stroke engine: teaching advance vs. retrieval practice	Written (chat box): Ci(-0.47), Ti(0.08)
Lachner et al., 2021, Exp1			Four-stroke engine: teaching vs. fill-in-blank task	Written (text box): Ci(-0.32), Ti(0.26)

Study	Sample Size	Sample Age	Experimental Manipulation	Effect Sizes
Lachner et al., 2021, Exp2			Four-stroke engine: teaching advance vs. retrieval practice	Ci(0.11), Ti(0.07)
Lim et al., 2021			Doppler effect: teaching vs. no activity	Ci*(1.12),* *Ti*(0.98)
Okita et al., 2013, Exp1			Doppler effect: teaching vs. retrieval practice	Cd*(0.84)
Orús et al., 2016			Educational technology: teaching vs. retrieval practice	Cd(-0.10)
Pi et al., 2020			Marketing introduction: teaching vs. restudying	Ci(-0.04), Ti(<0.01)
Rittle-Johnson et al., 2008			Multi-classification problem: teaching vs. restudying	Ci(0.44), Ti(-0.13)
van Brussel et al., 2021			Confirmation bias task: teaching vs. restudying	Ci*(0.13), Ti(0.21)
Wang et al., 2021			Doppler effect: imagined teaching vs. restudying	Ci*(0.56), Ti(0.34)

Note: C = comprehension performance; T = transfer performance; CE = cognitive load; M = motivation; E = enjoyment; SP = social presence; EL = elaboration statements; subscript i = immediate test; subscript d = delayed test; indicates self-generated teaching significantly outperformed control group ($p < 0.05$); _ indicates value not measured or missing.*

4. How Can the Effectiveness of Learner Self-Generated Teaching Be Theoretically Explained?

How can we theoretically explain the impact of self-generated teaching on learning? Currently, three non-mutually exclusive hypotheses focus on different ben-

eficial factors in self-generated teaching to explain its learning-promoting mechanisms: the retrieval practice hypothesis based on memory consolidation, the generative learning hypothesis focusing on generative cognitive processing, and the social presence hypothesis emphasizing social presence.

The retrieval practice hypothesis was the earliest to explain the effectiveness of self-generated teaching, proposing that it promotes learning mainly because learners spend substantial time actively retrieving previously studied material from memory during explanation (Koh et al., 2018). Koh et al. (2018) asked learners to record teaching videos by reading verbatim teaching scripts (self-generated teaching without retrieval practice) and found their learning performance similar to learners completing fill-in-the-blank tasks, suggesting that self-generated teaching no longer promoted learning. This may demonstrate the necessary role of retrieval practice. Memory research shows that retrieving information from long-term memory can change the memory representation of the retrieval itself—that is, alter how information is encoded—thereby strengthening memory traces and promoting retention of retrieved information, so self-generated teaching can consolidate memory (Carvalho et al., 2022; Zhou et al., 2013). Moreover, retrieving information from memory may help learners activate original and potentially relevant information, creating stronger memory cues or more retrieval pathways that are more easily activated, thereby increasing the likelihood of future successful retrieval and further promoting learning (Carvalho et al., 2022; Karpicke & Roediger, 2008; Rowland, 2014; Waldeyer et al., 2020; Liu et al., 2011). Our summary results partially support this hypothesis: among 17 comparisons using restudying as a control, 14 (82%) found self-generated teaching superior, while 3 (18%) found similar effects; however, among 17 comparisons using retrieval practice as a control, only 5 (29%) found self-generated teaching superior, while 12 (71%) found similar effects, suggesting retrieval practice and self-generated teaching may share similar mechanisms. Notably, 5 studies still found self-generated teaching more effective than retrieval practice (Hoogerheide et al., 2016, Experiment 2; Jacob et al., 2020; Lachner et al., 2020), indicating that other factors in self-generated teaching may also promote learning. Two main theoretical hypotheses have emerged to explain these additional beneficial factors.

Building on the retrieval practice hypothesis, the generative learning hypothesis posits that self-generated teaching involves not only information retrieval but also generative cognitive processing such as reasoning and integrating learning content (Fiorella & Mayer, 2015, 2016, 2022; Hoogerheide et al., 2019; Lachner et al., 2022). Koh et al. (2018) asked learners to read verbatim scripts when recording videos, which removed retrieval processes and severely impaired generative cognitive processing during teaching, thus failing to promote learning. Specifically, self-generated teaching (e.g., recording videos) may motivate learners to select the most important information from memory, organize it into coherent mental representations understandable to others, and integrate it with prior knowledge to construct meaningful and vivid knowledge structures. These generative processes help learners understand and apply knowledge (Fiorella &

Mayer, 2016, 2022; Mayer, 2021). Additionally, the demand for knowledge externalization during teaching helps learners elaborate on material while monitoring, evaluating, and reflecting on whether their current understanding and expression are accurate and comprehensive. These cognitive processes help learners build and strengthen meaningful connections between concepts and between material and prior knowledge, consolidating knowledge structures and ultimately improving learning outcomes (Fiorella & Mayer, 2015, 2016; Fukaya, 2013; Lachner et al., 2020, 2022; Lachner & Neuburg, 2018). Our summary results provide some support for this hypothesis. First, among 3 comparisons examining elaboration statements (one indicator of generative processing, e.g., Fiorella & Kuhlmann, 2020), 2 found self-generated teaching generated more elaboration statements and 1 found no difference, with a median effect size of $d = 0.85$, indicating that self-generated teaching effectively promotes generative cognitive processing. Second, transfer performance is a key indicator of generative processing, as reasoning, organizing, and integrating knowledge can improve transfer scores (Mayer, 2021). Our results show that self-generated teaching can improve transfer performance (d immediate $= 0.21$, d delayed $= 0.69$), partially supporting the generative learning hypothesis. Finally, numerous studies have found that learners generate more elaboration and monitoring statements during self-generated teaching, leading to better learning outcomes (e.g., Fiorella & Kuhlmann, 2020; Jacob et al., 2020, 2021, 2022; Lachner et al., 2020, 2021; Lim et al., 2021), suggesting the important role of generative cognitive processing.

The social presence hypothesis is a relatively recent perspective that emphasizes the role of perceiving potential others' presence (i.e., social presence) to extend the generative learning view, proposing that social presence level may affect the degree of generative processing. This hypothesis suggests that teaching to imagined audiences may engage learners in audience adaptation processes (Lachner et al., 2022). In other words, learners playing the teacher role tend to anticipate the audience' s knowledge base and consider whether the audience can understand their explanations, leading them to continuously adjust and optimize their content. These adaptive cognitive processes actually benefit learners' own knowledge mastery (Hoogerheide et al., 2019). Additionally, higher social presence (awareness of potential others' presence or psychological perception of others' "authenticity," Gunawardena, 1995; Kreijns, 2022) may trigger higher motivation and arousal (Hoogerheide et al., 2016). Motivation can incentivize learners to invest more mental effort to initiate and maintain cognitive processes such as selecting, retrieving, organizing, integrating, elaborating, and monitoring learning materials. Arousal can enhance working memory and memory consolidation, positively influencing learning (Arnsten, 2009; Roozendaal, 2002). Our summary analysis shows that self-generated teaching learners experienced higher social presence ($d = 2.05$) and motivation ($d = 0.44$) and invested more mental effort ($d = 0.45$), partially validating the social presence hypothesis. Moreover, oral forms with instructor presence (facing real people or camera, higher presence: d immediate comprehension $= 0.56$, d delayed comprehension $= 0.63$, d immediate transfer $= 0.35$, d delayed transfer $= 0.76$)

outperformed audio-only forms (no camera, lower presence: d immediate comprehension = 0.09, d immediate transfer = 0.02) and written forms (no camera, lower presence: d immediate comprehension = -0.16, d delayed comprehension = 0.39, d immediate transfer = 0.08, d delayed transfer = 0.19), further supporting this hypothesis. Studies also found self-generated teaching superior to generative learning activities without social context, such as self-explanation (Rittle-Johnson et al., 2008) and summary generation (Hoogeride et al., 2019), suggesting the unique role of social context.

In conclusion, the retrieval practice hypothesis and generative learning hypothesis focus on different subcomponents of cognitive processing (e.g., retrieval, generation, monitoring) to explain self-generated teaching' s positive effects, while the social presence hypothesis emphasizes that social presence may enhance overall cognitive processing to benefit learning. The basic viewpoints and relationships among these hypotheses are shown in Figure 2 [Figure 2: see original paper]. Currently, each hypothesis has received some support, indicating that self-generated teaching is not merely an instance of retrieval practice; generative cognitive processing and social presence may also play positive roles. However, since most studies focus on whether self-generated teaching promotes learning more than other common strategies rather than explicitly testing these hypotheses, the degree to which each factor contributes remains unclear (Fiorella & Kuhlmann, 2020; Hoogerheide et al., 2018, 2019; Lachner et al., 2022). Future research should directly and systematically examine the roles of retrieval practice, generative cognitive processing, and social presence in self-generated teaching and their interactions, ultimately developing an integrated theoretical model to more comprehensively explain its effects on learning.

Finally, while the three hypotheses above explain self-generated teaching from the perspective of effectively promoting learning, our results show that oral forms with instructor presence are most effective, while oral forms without instructor presence or written forms do not effectively promote learning. Therefore, we propose that the Cognitive Theory of Multimedia Learning (Fiorella & Mayer, 2015, 2016; Mayer, 2021, 2022) can also partially explain differences in how implementation methods affect learning, supplementing existing theoretical frameworks. Specifically, learners' limited processing capacity is primarily allocated to three processing demands: extraneous processing (consuming cognitive capacity without serving instructional goals), essential processing (representing learning content in working memory), and generative processing (reorganizing material and integrating it with relevant knowledge for deep understanding). On one hand, self-generated teaching implementation (e.g., video) may successfully create a teaching context, eliciting moderate social presence that guides learners to think more deeply about the material, increasing essential and generative processing and thus promoting learning. On the other hand, implementation methods (e.g., written language) may distract learners' attention to typographical errors or linguistic correctness and rigor (e.g., more complex sentence structures and grammatical components), increasing extraneous processing. Since generative activities themselves demand high processing capacity, excessive ex-

traneous processing may leave insufficient capacity for essential and generative processing, ultimately impairing learning. Audio-only self-generated teaching may fall between these extremes, where the weaker teaching context fails to significantly promote essential and generative processing, while the automaticity of spoken language does not add extraneous processing, resulting in minimal positive learning effects.

Figure 2. Theoretical explanations for the effects of self-generated teaching on learning

5. Summary and Outlook

From a knowledge construction perspective, the role transformation between "teaching" and "learning" in "teaching and learning promote each other" can facilitate knowledge acquisition. Learners' shift to an "instructor" role helps them actively construct knowledge, and learning through self-generated teaching can simply and efficiently achieve learning through teaching. Specifically, oral forms with instructor presence (e.g., video) effectively improve learning outcomes (d immediate comprehension = 0.56, d delayed comprehension = 0.63, d immediate transfer = 0.35, d delayed transfer = 0.76). In contrast, oral forms without instructor presence (e.g., audio only: d immediate comprehension = 0.09, d immediate transfer = 0.02) and written forms (e.g., text: d immediate comprehension = -0.16, d delayed comprehension = 0.39, d immediate transfer = 0.08, d delayed transfer = 0.19) show weak positive effects on learning outcomes. Additionally, self-generated teaching can increase learners' motivation (d = 0.44), enjoyment (d = 0.76), and effort investment (d = 0.47).

However, these conclusions represent overall trends. Through detailed literature analysis, previous studies show considerable heterogeneity. Combined with existing theoretical hypotheses, certain moderating variables may influence the learning-promoting effects of self-generated teaching, and it remains unclear which theoretical hypothesis best explains its impact. Therefore, future research should further explore the underlying mechanisms, boundary conditions, and ways to maximize the effectiveness of self-generated teaching, focusing on the following areas:

First, theoretical explanations for self-generated teaching's effects have not been directly and systematically validated. Since most previous studies did not test and compare different theoretical explanations, it remains unclear which factor —retrieval practice, generative processing, or social presence—plays the primary positive role. Future empirical research should adopt multi-factor experimental designs, manipulating multiple factors simultaneously. For example, researchers could vary material availability to manipulate retrieval practice levels while changing audience authenticity to manipulate social presence levels, directly revealing which factor has greater impact on learning. Additionally, based on our summary results and Cognitive Theory of Multimedia Learning, whether self-generated teaching implementation may create excessive extraneous processing

that hinders learning requires further investigation. Future studies should also include multiple process measures, such as physiological arousal (Hoogerheide et al., 2018; Pi et al., 2020), motivation levels (Wang et al., 2021; Hoogerheide et al., 2019), cognitive load (distinguishing types, Hoogerheide et al., 2016, 2018; Jacob et al., 2020, 2021), and generative processing (e.g., counting conceptual units, elaboration, and monitoring statements, Fiorella & Kuhlmann, 2020; Jacob et al., 2020; Lachner et al., 2020; Lim et al., 2021). Comprehensive analysis of multiple indicators can clarify which factors promote learning and their interrelationships and interactions, ultimately developing an integrated theoretical model to more comprehensively explain self-generated teaching' s effects and address the current limitation of fragmented theoretical explanations.

Second, based on our results, implementation method may be an important variable affecting learning. Current studies show substantial variation in implementation methods, including recording teaching videos (Hoogerheide et al., 2019), face-to-face teaching (Pi et al., 2020), recording teaching audio (Jacob et al., 2022), writing verbatim scripts (Lim et al., 2021), writing teaching explanations (Lachner et al., 2021), and imagined teaching (Wang et al., 2021). Differences between these methods have not received adequate attention. For example, studies comparing oral and written teaching effectiveness have used different combinations: recording videos vs. writing explanations (Hoogerheide et al., 2016), recording audio vs. writing explanations (Jacob et al., 2020), and recording videos vs. writing verbatim scripts (Lim et al., 2021). These different implementations may create varying levels of social presence and cognitive processing, leading to confounded results (Hoogerheide et al., 2016; Jacob et al., 2020, 2021; Lim et al., 2021). Future research should explore optimal implementation methods, further examining how different oral (or written) teaching methods create differences in social presence and cognitive processing that ultimately affect learning experience, explanation quality, and outcomes—for example, comparing video vs. audio recording, video teaching vs. online teaching vs. face-to-face teaching, and verbatim scripts vs. teaching explanations.

Third, based on the retrieval practice hypothesis, whether learners refer to learning materials or notes during teaching may affect the retrieval process across different implementation methods and thus influence the strategy' s effectiveness. On one hand, materials or notes can serve as cues to help learners explain content more comprehensively, and notes can help learners quickly identify important concepts, facilitating retrieval, elaboration, and mastery of key ideas (Hiller et al., 2020). On the other hand, material availability may inhibit learners' retrieval or active generation of information from memory, thus hindering knowledge consolidation and acquisition. For example, Okita et al. (2013) used fever knowledge as learning material, allowing learners to access and review materials during self-generated teaching, and found no learning benefits. Especially for written self-generated teaching, allowing learners to reference materials may lead them to passively copy material rather than actively generate explanations, substantially weakening effectiveness. Future research should examine how material availability (fully available, selectively available, or unavailable)

and presentation format (complete or condensed) affect the effectiveness of different self-generated teaching forms.

Fourth, based on the generative learning hypothesis, whether combining self-generated teaching with other learning strategies activates more generative processing and thus benefits learning—such as drawing (Learning-by-Drawing) or enacting (Learning-by-Enacting)—and whether different teaching implementation methods show different combination effects. Specifically, compared to oral explanation alone, drawing and enacting can help learners create external visual representations (Schmidgall et al., 2019), allowing them to externalize their thinking into the physical world (e.g., using pen, paper, or models) rather than relying solely on limited working memory resources. Moreover, transforming and organizing textual material into new spatial representations helps learners reason about and integrate material, and subsequently using these spatial representations to support verbal elaboration further promotes meaningful construction and refinement of verbal representations. Therefore, we might expect that the externalization and visualization functions of drawing and enacting could facilitate knowledge construction during oral teaching and improve the effectiveness of oral forms with instructor presence (Fiorella & Kuhlmann, 2020). However, written teaching already requires learners to engage in external visual representation to some extent, which occupies visual channels, and combining it with drawing or enacting may create competition for limited cognitive resources, potentially impairing effectiveness. Empirical research combining multiple generative learning strategies remains scarce. Future studies should examine whether combining self-generated teaching with other generative strategies further promotes or hinders learning, and whether teaching format, generative strategy type, and sequence of use play moderating roles.

Fifth, based on the social presence hypothesis, whether creating higher social presence can further enhance self-generated teaching's effectiveness and whether differences exist across implementation methods. Specifically, higher social presence may stimulate greater motivation, leading learners to invest more mental effort to initiate and maintain beneficial cognitive and metacognitive processes, thus facilitating learning. Higher social presence may also trigger higher arousal, promoting learning by enhancing working memory and memory consolidation. For example, for oral forms with instructor presence, future research could compare learning effects across conditions: recording videos for virtual audiences, online teaching for virtual audiences, online teaching for simulated audiences, online teaching for real audiences, and face-to-face teaching for real audiences, manipulating audience authenticity to vary social presence levels and explore optimal social presence for oral teaching. However, based on our analysis, for written forms, teaching itself already demands substantial cognitive load (written language is less automatic than spoken language), and increasing social presence may further increase cognitive load, potentially causing overload and impairing learning (Lachner et al., 2021). For example, Jacob et al. (2021) found that writing teaching explanations in a chat box for a real audience (higher social presence) did not improve learning compared to writing in a text box for

a virtual audience. Finally, considering the Yerkes-Dodson law, oral teaching effectiveness may not continuously increase with social presence (the relationship between motivation intensity and learning performance is often an inverted U-curve), making the exploration of optimal social presence levels for both oral and written forms a key issue for future research.

Sixth, whether adding interaction in self-generated teaching can help learners engage in more complete and thorough retrieval practice and generative cognitive processing during teaching, thereby improving explanation quality and learning outcomes (Lachner & Neuburg, 2018; Roscoe, 2014; Roscoe & Chi, 2008). Interacting with learners during teaching—for example, providing questions about the content or feedback on explanation quality—may help them identify gaps in their knowledge construction, enabling them to adjust and optimize retrieval, organization, and integration of material, refine mental representations, and improve learning outcomes (Roscoe, 2014; Roscoe & Chi, 2008). For example, Lachner and Neuburg (2018) had learners engage in written self-generated teaching and revise their explanation quality, then provided one group with concept-map feedback on their explanation quality while the control group received no feedback. The feedback group produced more coherent and cohesive explanation texts and achieved better transfer performance. Future research should explore what types of interaction and how to promote deep interaction to enhance self-generated teaching effectiveness. Additionally, whether interactions between teaching format and interaction exist—for example, whether oral teaching with instructor presence (e.g., face-to-face communication or video chat) generates more timely, accurate, and deep interaction than written teaching without instructor presence (e.g., sending messages)—requires further investigation.

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Note: Figure translations are in progress. See original paper for figures.