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The "Silent Teacher": Learning by teaching via writing a verbatim teaching script

Kagen Y. L. Lim | Sarah Shi Hui Wong | Stephen Wee Hun Lim

Department of Psychology, Faculty of Arts & Social Sciences, National University of Singapore, Singapore

Correspondence
Stephen Wee Hun Lim, Department of Psychology, Faculty of Arts & Social Sciences, National University of Singapore, Block AS4, Level 2, 9 Arts Link, Singapore 117570.
Email: psylimwh@nus.edu.sg

Abstract

Learning by teaching others is a potent educational strategy, but its implementation is typically cumbersome. This study ($N = 108$) investigated "silent teaching"—writing a verbatim teaching script—as a convenient approach for independent learning, while assessing whether the teaching benefit is a production benefit. Learners studied a science text on the Doppler effect using one of three learning methods: (1) generating and studying their own notes (restudying control), (2) preparing to teach and then verbally teaching (verbal teaching), or (3) preparing to teach and then writing a verbatim teaching script (silent teaching). On a conceptual knowledge retention test 1 week later, participants who wrote teaching scripts performed as well as those who taught verbally; both teaching groups outperformed control learners. Verbal and silent teaching significantly increased social presence and elaboration to comparable extents, relative to restudying. "Silent teaching" is a promising and efficient alternative learning approach to traditional verbal teaching.

KEYWORDS
explaining, generative learning, learning by teaching, production effect, social presence, writing to learn

1 | INTRODUCTION

Over recent decades, cognitive and educational psychologists have discovered several effective techniques for enhancing learning (Dunlosky et al., 2013; Roediger & Pyc, 2012). Of particular interest, learning by teaching is a potent educational strategy that improves one's understanding of studied material through the act of teaching it to others (Fiorella & Mayer, 2015, 2016). For instance, preparing to teach has been shown to increase learners' metacognitive self-regulation, conceptual formulation of problems and, eventually, their ability to solve those problems (Muis et al., 2016). Not only does learning increase when students study with the expectation to teach rather than to be tested (Guerrero & Wiley, 2021; Nestojko et al., 2014), but actually teaching the material produces further learning gains (Fiorella & Mayer, 2013, 2014; Hoogerheide et al., 2014) and enjoyment for students (Hoogerheide et al., 2019).

From a psychological perspective, there are three promising accounts for the learning benefits of teaching. First, the *retrieval hypothesis* posits that teaching involves substantive retrieval of the material from memory, thereby enhancing the teacher's own learning (Koh et al., 2018; Lachner et al., 2020). Second, the *generative hypothesis* suggests that teaching encourages generative processing that aids the teacher's learning when organizing and elaborating on the material by drawing connections and integrating the content with one's existing knowledge structures (Fiorella & Mayer, 2016; Roscoe & Chi, 2008), while monitoring one's understanding (Lachner et al., 2020). Third, the *social presence hypothesis* postulates that maintaining a fictitious audience in mind to whom the teaching is delivered elicits useful adaptation processes when the teacher must tailor their explanations based on their estimations of their audience's prior knowledge (Clark & Brennan, 1991; Nickerson, 1999; Schober & Brennan, 2003; Wittwer et al., 2010; for a discussion, see Lachner et al., 2021).

Despite the growing empirical evidence for learning by teaching as an effective educational strategy (see Fiorella & Mayer, 2016 for a review), few studies have examined the ways that it can be more

efficiently implemented in support of students' independent learning. Independent learning involves taking charge of one's own learning, selecting and setting one's own goals, deciding what, when and how best to learn, and tracking one's own progress (Hockings et al., 2018). Being able to learn independently has been viewed as crucial for becoming sophisticated learners—it is integral in enabling students to effectively manage their own studies outside of formal classroom settings without requiring expensive technologies or extensive instructor-provided materials and supervision (Bjork et al., 2013; Dunlosky et al., 2013), and to determine when and how best to engage with the course material in online learning environments (Kizilcec et al., 2017). Moreover, independent learning may become indispensable as our world continues to orient toward a model of remote teaching and learning, especially given the ongoing COVID-19 situation. However, learning by teaching has, at present, largely adopted the format of peer tutoring (e.g., Roscoe & Chi, 2007, 2008) or delivering video lectures to a fictitious audience (e.g., Hoogerheide et al., 2014). Thus, willing peers (or teachable agents in computer-based learning environments) and logistically cumbersome equipment (e.g., video-recording tools and software) have, up until now, been necessitated in the learning by teaching process. These requirements may present barriers that constrain students' independent use of this technique across more diverse educational contexts. Hence, the present research aimed to discover a sustainable—less resource-intensive—alternative to conventional learning by teaching that could be readily applied as an independent learning tool.

A concurrent goal was to investigate the extent that the teaching effect is a "production effect". Recent research has revealed that the mere act of verbalizing words aloud, as opposed to reading them silently, increases their distinctiveness and subsequent retrievability, thereby enhancing memory and learning (see MacLeod & Bodner, 2017 for a review). It remains to be known, though, whether production undergirds other (applied) cognitive processes. Of current interest, to what extent are the learning benefits of teaching attributable to the verbalization involved during one's teaching?

2 | SILENT TEACHING

A promising candidate to be pitted against traditional verbal teaching is *silent teaching*—writing verbatim teaching scripts as exact transcripts of how one would deliver a lesson. In the present context, writing involves the act of teaching, but in a written rather than oral modality (Jacob et al., 2020). In other words, verbatim teaching scripts are not merely written essays or expository prose per se, but constitute "written teaching" where learners must translate the content to an audience exactly as how they would orate an actual lecture verbally. In contrast to writing instructional explanations that are precisely meant to be communicated in written form to an intended audience, writing verbatim teaching scripts involves transcribing speech to text for what is originally meant to be an orally communicated lecture. Thus, beyond written discourse, verbatim teaching scripts may draw on spoken discourse that is typically evoked during verbal teaching (for discussions of spoken and written discourses, see Jahandarie, 1999; Sindoni, 2013).

Surprisingly, though, whereas a growing number of studies have investigated the effects of writing explanations (e.g., Gunel et al., 2009; Hoogerheide et al., 2016; Jacob et al., 2020; Lachner et al., 2018, 2021), the literature appears to be largely silent on the prospect of writing verbatim teaching scripts as a viable alternative to conventional verbal teaching. Whilst being relatively easier to implement in and beyond the classroom as an independent learning activity without the need for technical equipment or a physically present audience, silently generating a written teaching script may be just as effective as verbal teaching.

Consistent with this notion, some studies have found that learners displayed comparable comprehension performance after reading a prose passage either verbally or silently (McCallum et al., 2004; Miller & Smith, 1985). Likewise, the mechanisms underlying the learning benefits of verbal teaching may extend to silent teaching, thereby yielding similar learning gains. For instance, the advantages of verbal teaching for the teacher's own comprehension have been attributed to the deep cognitive processing that teaching promotes (Fiorella & Mayer, 2013, 2014). Presumably, when teaching or explaining material to others, learners engage in reflective knowledge building through selecting relevant information, organizing information appropriately, metacognitively monitoring comprehension, and synthesizing new knowledge with their prior knowledge. Plausibly, these beneficial processes may also be elicited during silent teaching, in view that learners must similarly bear their target audience in mind when generating a verbatim teaching script, just as they would during verbal teaching. Indeed, being aware of a fictitious audience and perceiving that audience to be "real" increases social presence, which may foster the teacher's own effective learning even without actual interaction with the audience (Gunawardena, 1995; Short et al., 1976). To the extent that similar social presence is evoked when learners bear a target audience in mind whilst teaching—verbally or silently through script-writing, their learning may be similarly boosted.

3 | THE PRESENT STUDY

Here, we pursued and investigated an independent mode of learning by teaching in the form of "silently" generating a verbatim teaching script, as opposed to conventional verbal teaching. The view is that verbatim teaching scripts constitute a written modality of oral-based (verbal) teaching, which can be suitable for independent learning purposes relative to students' "business-as-usual" strategies such as restudying (Dunlosky & Rawson, 2015; Karpicke, 2009). In addition, whereas researchers have often tested learners right after they have taught, the test in the present study was conducted after a 1-week delay to assess durable, long-term learning, in line with testing in real-world educational settings that typically takes place after a time interval, rather than immediately after study.

In this research, learners were prescribed a science text on the Doppler effect, and either (1) did not teach but prepared to be tested by studying the text whilst generating their own notes for 12 min,

before surrendering the text and studying their notes for another 4 min (*control* group), (2) prepared to teach by studying the text and generating teaching notes for 12 min, before teaching verbally for 4 min whilst being video-recorded for a target learner audience (*verbal teaching* group), or (3) prepared to teach by studying the text and generating teaching notes for 12 min, before writing a verbatim teaching script for 4 min whilst expecting the script to subsequently reach a target learner audience (*silent teaching* group). In view that the learning benefits of teaching have recently been ascribed, in part, to retrieval practice when teaching unaided from memory (Koh et al., 2018), we dissociated the benefits of teaching versus retrieval by insuring that participants had access to their self-generated notes in both the verbal and silent teaching conditions. This way, participants would not retrieve information from memory when teaching, thereby ruling out any alternative interpretations that the learning benefits of teaching in our study might be attributable to retrieval practice.

We investigated the effects of all three techniques on durable, long-term learning by administering a conceptual knowledge retention test to all learners after a 1-week delay. To the extent that the teaching effect is not a production effect, and that verbally teaching versus writing a verbatim teaching script for a target audience similarly elicit social presence that prompts reflective knowledge building, we predicted that both teaching strategies would be equally effective in boosting learners' conceptual knowledge retention, relative to restudying.

We further measured the frequency of audience-directed utterances in each condition as a behavioral proxy of the degree of social presence that each learning method elicited. Specifically, we scored the percentage of self-other referential terms (e.g., 'I', 'me', 'you', 'us', 'let's', 'our', 'we', 'your', and 'yourself') contained in participants' verbal teaching, written teaching scripts, or study notes (for similar approaches, see Chafe, 1982; Lachner et al., 2018; Redeker, 1984). We expected that social presence would be just as effectively induced during silent versus verbal teaching, and that learners in both teaching conditions would display more frequent audience-directed utterances (i.e., higher social presence) than those in the control condition. Indeed, although both the silent teaching and control conditions involved generating written responses, self-other referential terms would be more likely to be used in verbatim teaching scripts that are written for a target audience, as opposed to study notes that are written for the self. Accordingly, if silent teaching outperforms the control condition, then this learning benefit may at least be partially attributable to processes arising from increased social presence, as indicated by the greater use of self-other referential terms induced by teaching (e.g., Jacob et al., 2020).

4 | METHOD

4.1 | Participants

A total of 108 students (24 male, 82 female, two undisclosed), aged between 18 and 28 ($M = 20.67$, $SD = 1.85$), from the National University of Singapore (NUS) took part in the study. Participants received either course credit for an introductory psychology module or monetary remuneration for an hour of participation. As the study material related to the Doppler effect, students who majored in Physics were excluded from participation. This research was conducted with the appropriate ethics review board approval by NUS and the participants' informed consent.

A sensitivity analysis (G*Power; Faul et al., 2007) indicated that the present sample afforded sufficient sensitivity to detect medium effects ($f \geq 0.27$) for between-subjects pairwise contrasts at $\alpha = .05$ and power $= .80$, in line with previous studies that reported medium effects of oral explaining versus restudy on learners' delayed test performance (e.g., Fiorella & Mayer, 2014; for a meta-analysis, see Kobayashi, 2019).

4.2 | Design

We employed a between-subjects design with instructional method as the independent variable. Participants were randomly assigned to one of three learning conditions: (1) *control* condition in which participants prepared to be tested by studying the text and generating their own study notes, (2) *verbal teaching* condition in which participants prepared to teach by generating teaching notes whilst studying the text, and subsequently verbally taught with a target audience in mind whilst accessing their notes and being filmed, or (3) *silent teaching* condition, in which participants prepared to teach by generating teaching notes whilst studying the text, and subsequently wrote a verbatim teaching script with a target audience in mind whilst accessing their notes. The dependent variable was long-term conceptual knowledge retention, measured as participants' performance on a recall test administered 1 week later.

4.3 | Materials

4.3.1 | Prior knowledge measure

As in Fiorella and Mayer (2013, 2014), participants indicated their prior knowledge of the Doppler effect on a 5-point scale (1 = *very low*; 5 = *very high*), and whether each of the following eight content items applied to them: (1) "I have taken a University course in Physics"; (2) "I know what Hertz (Hz) means"; (3) "I have used an oscilloscope"; (4) "I know how radar works"; (5) "I know the basic characteristics of sound waves"; (6) "I know what relative motion is"; (7) "I know what the red shift is"; (8) "I know what a sine curve is". Participants' ratings were summed (i.e., one point was awarded for each of the eight statements that applied to them, plus their response on the 5-point rating scale) to derive a measure of prior knowledge, with a maximal possible score of 13 points.[1] Participants also indicated their perceived ability to perform on a Doppler effect test on a 5-point scale (1 = *very poorly*; 5 = *very well*).

4.3.2 | Doppler effect lesson

The study text detailed the key concepts of sound waves and how the Doppler effect works (adapted from Fiorella & Mayer, 2013, 2014; see Supplementary Material). This lesson comprised a total of 585 words and five graphical figures, with a Flesch Reading Ease score of 66.6 and Flesch–Kincaid Grade Level of 8.0.

4.3.3 | Post-experimental questionnaire

Participants provided ratings for eight phenomenological items (adapted from Fiorella & Mayer, 2013, 2014). These items measured their subjective experiences during learning on a 7-point scale (1 = *strongly disagree*; 7 = *strongly agree*) in terms of (1) the difficulty of the subject matter ('*difficult*'); (2) how much they enjoyed the learning ('*enjoyment*'); (3) how much they would like to learn with the learning method in the future ('*future*'); (4) their perceived understanding of the Doppler effect ('*understand*'); (5) their interest to know more about the Doppler effect ('*interest*'); (6) how useful they found the Doppler effect lesson ('*useful*'); (7) how stressed they felt during the learning process ('*stress*'); (8) the mental effort ('*effort*') they invested during the experiment.

4.4 | Procedure

The study involved two sessions spaced 1 week apart. In the first session, participants foremost provided their informed consent and demographic details (age, gender, and year of study), and completed the prior knowledge measure. All participants were then told that they would be studying a lesson on the Doppler effect for a total of 16 min, and that they would be tested on what they had learned 1 week later, although the actual test format was not disclosed. Participants were then randomly assigned to one of the three learning conditions: *verbal teaching*, *silent teaching*, or *control*.

Participants in both the verbal teaching and silent teaching conditions were informed that they had 12 min to study the text on the Doppler effect and to prepare teaching notes, before generating a 4-min lesson about the Doppler effect. After 12 min, the experimenter collected the text from participants, but allowed them to keep their teaching notes. Participants in the verbal teaching condition then delivered a 4-min video lecture that was recorded using a mobile phone. A whiteboard and markers were provided should they deem these items to be useful for enhancing their lecture delivery. Conversely, participants in the silent teaching condition were given 4 min to write a verbatim (i.e., word-for-word) teaching script as how they exactly would deliver an actual lecture if they generated it verbally. Control participants, like their counterparts in the two teaching-related conditions, were informed that they had 12 min to generate notes based on the Doppler effect text for the purposes of their own learning in preparation for the test. After 12 min, they returned the text to the experimenter, and were given 4 min to revise and refine their own notes to their best abilities. After which, all participants completed the post-experimental questionnaire and were reminded about the second session.

One week later, participants returned and were briefed about the duration, format, and nature of the conceptual knowledge retention test. Specifically, participants were instructed to accurately recall and write down as many key concepts, graphical representations, and explanations contained in the lesson on the Doppler effect as they could (e.g., Karpicke & Blunt, 2011; Roediger & Karpicke, 2006). The test lasted 5 min. Upon completion, participants were debriefed and thanked for their participation.

5 | RESULTS

5.1 | Scoring

Two raters who were blind to the experimental conditions independently scored 10 out of 108 of the test scripts for participants' conceptual knowledge retention test performance, use of self-other referential terms, and number of elaborations generated. Discrepancies were reviewed and resolved through discussion to reach 100% agreement. As interrater reliability was high across all three scoring components, the remaining scripts were scored by one rater.

5.2 | Conceptual knowledge retention

A standardized marking rubric was applied to score participants' responses on the conceptual knowledge retention test according to their ability to recall key concepts and definitions, as well as graphical representations and their accompanying explanations. One point was awarded for each idea unit that participants correctly recalled, with a maximum possible score of 24. Interrater reliability was high, with absolute agreement intraclass correlation (ICC) = .98, 95% CI [.935, .995] based on a two-way random-effects model.

5.2.1 | Social presence

As a proxy for social presence, we scored the frequency of self-other referential terms (e.g., 'I', 'me', 'you', 'us', 'let's', 'our', 'we', 'your', and 'yourself') as a percentage of the total number of words contained in participants' verbal teaching, teaching scripts, or study notes (e.g., Chafe, 1982; Lachner et al., 2018; Redeker, 1984). Interrater reliability was excellent, ICC = 1.00.

5.2.2 | Elaborations

To assess the quality of participants' explanations, we scored the number of elaborations in their verbal teaching, teaching scripts, or study notes as a behavioral indicator of generative processing

(Fiorella & Mayer, 2016; Roscoe & Chi, 2008). An elaboration was operationalized as an idea unit that was not covered in the study text, including examples, analogies, and personal experiences (Fiorella & Kuhlmann, 2020; Jacob et al., 2020; Lachner et al., 2018). Interrater reliability was excellent, ICC = .95, 95% CI [.828, .987] based on a two-way random-effects model.

5.3 | Preliminary analyses

A chi-square test was conducted to determine whether the distribution of gender and year of study was comparable across the three learning conditions. There was no significant difference in gender distribution, χ^2 (2) = 4.09, p = .13, although the distribution of year of study differed, χ^2 (8) = 29.94, p < .001. To ensure that year of study did not drive any differences in test performance across learning conditions, we ran a 5 (year of study) × 3 (instructional method) ANOVA with participants' conceptual knowledge retention test scores as the dependent variable. Indeed, there was no interaction between year of study and instructional method, F(6, 94) = 0.70, MSE = 8.90, p = .65, η_p^2 = .043, indicating that the relationship between instructional method and test performance did not systematically vary across learners' year of study. In addition, we ascertained via one-way ANOVAs that participants across learning conditions did not significantly differ in their perceived ability, F(2, 105) = 0.31, MSE = 0.91, p = .73, η_p^2 = .006, and self-reported prior knowledge of the Doppler effect, F(2, 105) = 1.92, MSE = 5.09, p = .15, η_p^2 = .035. Means and standard deviations are presented in Table 1. Neither perceived ability nor prior knowledge correlated with participants' test performance, both ps > .05.

TABLE 1 Means and standard deviations (SDs) of participants' ratings on prior knowledge measure and post-experimental questionnaire

	Mean ratings		
Item	**Control**	**Verbal teaching**	**Silent teaching**
Prior knowledge measure			
Prior knowledge	3.41 (1.79)	4.36 (2.84)	4.29 (1.89)
Perceived ability	2.24 (1.02)	2.41 (0.99)	2.31 (0.83)
Post-experimental questionnaire			
Difficult	2.44 (1.37)	3.23 (1.58)	2.89 (1.64)
Enjoyment	5.53 (1.08)	5.31 (1.26)	5.29 (1.18)
Future	5.26 (1.14)	5.00 (1.36)	4.94 (1.30)
Understand	5.62 (1.10)	5.38 (1.41)	5.46 (1.24)
Interest	4.53 (1.56)	5.03 (1.35)	4.57 (1.67)
Useful	4.38 (1.33)	5.00 (1.41)	4.94 (1.61)
Stress	2.74 (1.60)	4.00 (1.93)	3.23 (1.68)
Effort	4.41 (1.50)	4.49 (1.34)	4.29 (1.67)

Note: SDs appear in parentheses. The maximum possible score for prior knowledge was 13. Perceived ability ratings were made on a 5-point scale. All other ratings on the post-experimental questionnaire were made on a 7-point Likert scale.

5.4 | Main analyses

5.4.1 | Conceptual knowledge retention

A one-way ANOVA revealed a significant main effect of instructional method on conceptual knowledge retention, F(2, 105) = 3.66, MSE = 8.70, p = .03, η_p^2 = .065. As predicted, participants in both the verbal teaching (M = 8.33, SD = 3.03) and silent teaching (M = 8.11, SD = 3.26) conditions outperformed control (M = 6.59, SD = 2.48) participants, p = .01 and .03, d = 0.63 and 0.53, respectively. Crucially, participants who verbally taught versus wrote a verbatim teaching script did not significantly differ in their test performance, p = .77, d = 0.07. Thus, verbal teaching and silent teaching were just as effective in enhancing long-term conceptual knowledge retention, over restudying (see Figure 1).

5.4.2 | Social presence

The percentage of self-other referential terms in participants' verbal teaching, teaching scripts, and study notes significantly differed, F(2, 102) = 32.02, MSE < 0.001, p < .001, η_p^2 = .39.[2] Specifically, learners who taught verbally (M = 3.99%, SD = 1.51) or generated a verbatim teaching script (M = 3.79%, SD = 2.85) used a significantly greater proportion of self-other referential terms, relative to control learners (M = 0.58%, SD = 1.02), both ps < .001, d = 2.61 and 1.48, respectively. Both teaching groups did not differ in the proportion of self-other referential terms used, p = .70, d = 0.09. Hence, verbal and silent teaching increased social presence significantly and to comparable extents, relative to the control method.

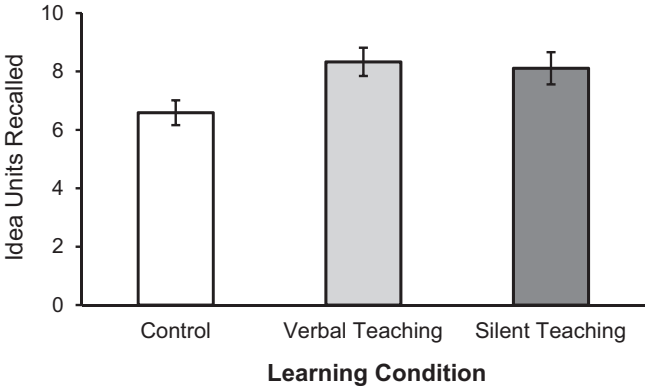

FIGURE 1 Conceptual knowledge retention performance across learning conditions. *Note:* Conceptual knowledge retention was measured as the number of idea units from the study text that learners correctly recalled on a delayed test 1 week later. The maximum possible score was 24. Error bars denote standard errors

5.4.3 | Elaborations

Likewise, the number of elaborations in participants' verbal teaching, teaching scripts, and study notes significantly differed, $F(2, 102) = 11.73$, $MSE = 3.83$, $p < .001$, $\eta_p^2 = .19$.[2] Specifically, learners who taught verbally ($M = 2.74$, $SD = 2.46$) or wrote a verbatim teaching script ($M = 1.83$, $SD = 2.01$) generated more elaborations than control learners ($M = 0.47$, $SD = 0.98$), both $ps < .001$, $d = 0.85$ and 1.18, respectively. Both teaching groups did not differ in their number of elaborations generated, $p = .09$, $d = 0.40$. Thus, verbal and silent teaching significantly increased elaboration (i.e., induced greater generative processing) and to comparable extents, relative to the control method.

5.4.4 | Phenomenological items

We employed one-way ANOVAs to analyze participants' responses on the phenomenological items in the post-experimental questionnaire. Means and standard deviations are presented in Table 1. Participants' self-reported stress ratings differed across learning conditions, $F(2, 105) = 4.85$, $MSE = 3.07$, $p = .01$, $\eta_p^2 = .085$. Specifically, verbal teaching participants reported significantly higher stress ($M = 4.00$, $SD = 1.93$) than control participants ($M = 2.74$, $SD = 1.60$), $p = .004$, $d = 0.71$, but not silent teaching participants ($M = 3.23$, $SD = 1.68$), $p = .073$, $d = 0.42$. There were no other significant differences across conditions for all other variables, all $ps > .05$. Notably, in contrast to their actual test performance, participants' ratings of how much they would like to learn with their respective instructional method in the future did not differ across conditions. That is, participants did not report a stronger preference to use any particular method, despite the fact that the teaching-related methods were more useful for their long-term conceptual knowledge retention. In addition, none of the phenomenological items (including stress) correlated with participants' test performance, all $ps > .05$.

6 | DISCUSSION

Learning by teaching has been shown to enhance the teacher's own learning, although the prospect of more efficiently implementing this technique in students' independent learning has seldom been examined in current literature. Here, we proposed an independent, written mode of learning by teaching via silent teaching—writing a verbatim teaching script whilst bearing a target learner audience in the teacher's mind, and tested the extent that silent teaching enhances long-term learning as does conventional verbal teaching, relative to restudying.

Our results revealed that learners who engaged in either verbal or silent teaching outperformed those who generated and restudied notes during a conceptual knowledge retention test 1 week later, with verbal and silent teaching producing comparable benefits. In view that verbal teaching did not offer additional learning gains over silent teaching, these findings provide evidence that the teaching benefit is *not* merely a production—verbalization—benefit. Rather, silent teaching is just as effective, and potentially more viable, for promoting durable learning. In particular, silent teaching is advantageous in practical terms, in that it can be readily and efficiently applied as a relatively less resource-intensive means of independent learning.

The present data further revealed that teaching, whether verbally or silently, led to heightened social presence, as indicated by more frequent use of audience-directed utterances (e.g., 'you' or 'we'), as well as greater generative processing, as indicated by the production of more elaborations that were not directly stated in the study material, relative to writing and reviewing study notes in the control condition. Crucially, silent teaching effectively enhanced social presence and elaboration to similar extents as did verbal teaching. This observation is compatible with past reports on asynchronous online teaching and learning, which have suggested that social presence can be established via written text alone (e.g., Andresen, 2009), notwithstanding the lack of visual and vocal cues (cf. Garrison et al., 2000; Tu & McIsaac, 2002). In turn, greater social presence may bolster the teacher's own learning by encouraging reflective knowledge building, such as constructively building on one's prior knowledge by generating more elaborations or inferences during one's teaching (Roscoe & Chi, 2007). For instance, teaching (fictitious) others—whether verbally or silently—may encourage the teacher to construct a richer mental model of the material that detects and distinguishes between concepts that are better versus more poorly understood, to select what material to present, as well as to coherently reorganize and express the selected content so that it can be easily understood by one's audience (Coleman et al., 1997; cf. Lachner et al., 2021, Roscoe & Chi, 2008). These processes may then foster the teacher's own deeper learning and mastery of the to-be-taught material, even without interacting with one's audience during teaching.

6.1 | Theoretical implications

The current findings are particularly intriguing when juxtaposed with those of recent studies on learning by explaining, which have typically found an advantage of generating oral explanations over written explanations in increasing social presence and, correspondingly, learning performance (e.g., Hoogerheide et al., 2016; Jacob et al., 2020; Lachner et al., 2018). For instance, Jacob et al. (2020) observed that generating oral explanations produced better learning than written explanations—an advantage that was mediated by higher levels of social presence (i.e., the use of more personal references) in their oral explanation condition that triggered generative processes when formulating more comprehensive explanations, thereby promoting learners' comprehension. In contrast, the silent teaching condition in the present study induced social presence and elaboration as effectively as did verbal teaching, which may then have boosted learning equally across both the teaching conditions.

Considered in tandem, these findings provide further insights for the social presence hypothesis, whereby the relative effectiveness of

written versus oral modalities of learning by teaching may hinge, at least in part, on how well they elicit social presence. In view that social presence has been implicated in mediating the learning effects of explaining modality by triggering greater generative processes during explaining (Jacob et al., 2020; Lachner et al., 2018), it logically follows that writing explanations would produce correspondingly poorer learning performance when it does not elicit social presence as effectively as oral explaining does. Conversely, when social presence is effectively increased to similar degrees across both oral and written modalities, then as the present study has demonstrated, even written ("silent") teaching can be just as potent for learning as verbal teaching.

Why did writing verbatim teaching scripts induce social presence as effectively as verbal teaching in the present study? Writing verbatim teaching scripts involves transcribing speech to text for a lecture that one would originally communicate orally, and this written modality of teaching may evoke oral-based mechanisms that overlap with those of conventional verbal teaching. For instance, the following is a sample excerpt from a participant's written *verbatim teaching script* ("*silent teaching*"):

> Today, we'll be studying the Doppler Effect. You might not realize that actually, we witness this effect quite often in our lives. Say, for example, have you ever noticed that a police car with its siren on will sound higher-pitched when it's approaching us and will sound lower-pitched as it leaves us? That's the Doppler effect in action. However, before we dig into the mechanisms of the Doppler effect, let me start by telling you the ingredients of a sound wave.

In comparison, the following is a sample excerpt from a participant's *verbal teaching*:

> Hi everyone, today we're going to talk about the Doppler effect. For those of you that don't know what the Doppler effect is, maybe you've been on the side of the road while a fire engine passes by and it goes "wewwewwew". Therefore, if you notice, there's something very specific about the sound that's happening and we'll talk about what that is in a bit. But first, let's break down some qualities of sound.

Without being informed that these excerpts had been written versus orally delivered, naïve readers may be hard-pressed to differentiate between them.

Indeed, as alluded to in the Introduction, one key feature of verbatim teaching scripts is that they may draw on spoken discourse that is typical of verbal teaching, in contrast to typical written prose. Spoken discourse (e.g., conversation) often reflects relatively more focus on interpersonal involvement than written discourse (e.g., expository prose), which tends to reflect relatively more focus on content (Tannen, 1985). In turn, this distinction between the relatively greater focus on involvement versus content, as opposed to oral versus written modalities per se, may account for the varying effects of spoken versus written language (Tannen, 1983). That is, strategies that have been characterized as "oral" in building on interpersonal involvement may be used for successful discourse in not only the spoken mode, but also the written mode (Tannen, 1983). In the present context, verbatim teaching scripts may be one such example of how typically "oral" strategies can be implemented in the written modality to enhance social presence and elaboration, which are vital for effective learning by teaching. Future research may directly compare the effects of writing verbatim teaching scripts versus expository explanations, while exploring further ways that writing-based teaching can be designed to evoke strong social presence and elaboration to maximize learning gains.

6.2 | Educational implications

Teaching non-present, anonymous others asynchronously has become common practice in contemporary online learning environments (Andresen, 2009; Borup et al., 2013). Our data show that learners' long-term conceptual knowledge retention can profit from not only conventional verbal teaching, but also silent teaching. This suggests that learners or tutors may be exempted from the immediate need for peers or logistical resources in adopting the learning by teaching technique. Instead, learners may simply write a full verbatim teaching script to learn just as effectively. Importantly, silent teaching can be readily implemented to foster independent learning not only in classroom instruction, but also in informal educational settings where learners take ownership of their own learning in their preferred time and space.

Yet, in contrast to their actual test performance, learners in our study displayed no preference for learning with verbal or silent teaching in the future, relative to restudying. This suggests that students may not be aware that teaching promotes their learning, and thus may not go on to adopt this method during their own study in real-world settings. Our finding echoes those of several studies on other potent techniques in learning (e.g., Karpicke et al., 2009; Yan et al., 2016), which have observed that students often do not use strategies that cognitive researchers have identified as effective. Hence, it may be particularly important for teachers to explicitly encourage and guide their students to adopt this instructional method for enhanced learning.

6.3 | Future directions

Whereas the present research focused specifically on the benefits of silent versus verbal teaching for students' long-term conceptual knowledge retention, it would be valuable for future work to ascertain the extent that these benefits also apply to other learning outcomes, such as those involving higher-order cognitive processes. Indeed, building a basic foundation of factual knowledge does not necessarily mean that students will be able to successfully transfer their learning

to apply, analyze, evaluate, or even create knowledge (Agarwal, 2019). For instance, whereas written explanations tend to be better organized than verbal explanations and thus facilitate conceptual knowledge acquisition, verbal explanations may benefit transfer of learning in contexts when they induce greater social presence that triggers generative processing to a more pronounced extent (Chafe, 1982; Jacob et al., 2020; Lachner et al., 2018; Redeker, 1984). Accordingly, validating the learning benefits of silent teaching across a wider range of educational contexts will be a fruitful avenue for future research, in order to understand how and when best to implement this technique. In view that learners' long-term retention performance across all learning conditions was relatively low after a 1-week delay, it may also be worthwhile for future work to investigate how the efficacy of teaching activities can be further boosted—for instance, by training learners to improve the quality of their teaching—for greater long-term learning gains.

Finally, learners are susceptible to a knowledge-telling bias, and may tend to merely state or summarize what is already written in the to-be-taught material with little elaboration or self-monitoring (Roscoe & Chi, 2007, 2008). This bias may be overcome through interacting with others, implicating the importance of a target audience. Yet, it should be noted that teachers may not adequately adapt their teaching to suit and benefit their audience's unique learning needs when teaching an imagined audience (see Lachner et al., 2020 for a discussion). In principle, teachers might thus stand to gain from first knowing their (imagined) audience's current knowledge level. This way, the teachers may be better guided to engage in reflective knowledge building when monitoring whether their (imagined) students could follow and understand their teaching. The extent that gaining such overt information as students' current knowledge level will enhance teachers' abilities to teach—verbally or silently—and in turn boost their knowledge gains from teaching remains an open question for future inquiry.

7 | CONCLUSION

Amidst a rapidly changing educational landscape, our pedagogical methods must continue to adapt, evolve, and rise to the challenge. As a resource to support students' independent learning even outside of formal classroom settings, the present study innovated the learning technique of "silent teaching" via writing a verbatim teaching script. Adding to the thriving cognitive-educational psychology literature on effective and inexpensive techniques that enhance learning (Roediger & Pyc, 2012), we demonstrated that silent teaching is one such instructional method that shows promise for independent learning by teaching. The present results reveal that verbalization per se is tangential to teaching, and enable a fuller understanding of how learning by teaching can be flexibly and efficiently implemented, whilst illuminating its potential applications for real-world educational practice. Future research should consider how silent teaching might benefit and be best adopted by learners for various independent learning settings and educational goals.

AUTHORS CONTRIBUTION

The research concept came from Stephen Wee Hun Lim. Kagen Y. L. Lim performed the data analysis and interpretation under the supervision of Stephen Wee Hun Lim. Kagen Y. L. Lim drafted the manuscript, and Sarah Shi Hui Wong and Stephen Wee Hun Lim provided critical revisions. All authors approved the final version of the manuscript for submission.

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CONFLICT OF INTERESTS

The authors declared no conflicting interests with respect to their authorship or the publication of this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Kagen Y. L. Lim https://orcid.org/0000-0003-4868-1127
Sarah Shi Hui Wong https://orcid.org/0000-0003-4243-212X
Stephen Wee Hun Lim https://orcid.org/0000-0003-3636-7587

ENDNOTES

[1] Extant literature warns that learners may not be able to accurately assess the extent of their own comprehension and learning (e.g., Prinz et al., 2020). At the same time, we cautiously refrained from directly testing learners' prior knowledge in circumventing retrieval effects in a learning-by-teaching context (Koh et al., 2018). Upon balanced deliberation, we opted for Fiorella and Mayer's (2013, 2014) self-reporting procedure as a relatively more indirect measure of learners' prior knowledge.

[2] One participant from the verbal teaching condition and two participants from the control condition were excluded due to technical malfunctions of the experimental material.

REFERENCES

Agarwal, P. K. (2019). Retrieval practice & Bloom's taxonomy: Do students need fact knowledge before higher order learning? *Journal of Educational Psychology*, *111*(2), 189–209. https://doi.org/10.1037/edu0000282

Andresen, M. A. (2009). Asynchronous discussion forums: Success factors, outcomes, assessments, and limitations. *Technology & Society*, *12*(1), 249–257.

Bjork, R. A., Dunlosky, J., & Kornell, N. (2013). Self-regulated learning: Beliefs, techniques, and illusions. *Annual Review of Psychology*, *64*, 417–444. https://doi.org/10.1146/annurev-psych-113011-143823

Borup, J., West, R. E., & Graham, C. R. (2013). The influence of asynchronous video communication on learner social presence: A narrative analysis of four cases. *Distance Education*, *34*(1), 48–63. https://doi.org/10.1080/01587919.2013.770427

Chafe, W. (1982). Integration and involvement in speaking, writing, and oral literature. In D. Tannen (Ed.), *Spoken and written language: Exploring orality and literacy* (pp. 35–53). Ablex.

Clark, H. H., & Brennan, S. E. (1991). Grounding in communication. In L. B. Resnick, J. M. Levine, & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 127–149). American Psychological Association. https://doi.org/10.1037/10096-006

Coleman, E. B., Brown, A. L., & Rivkin, I. D. (1997). The effect of instructional explanations on learning from scientific texts. *The Journal of the Learning Sciences*, *6*(4), 347–365. https://doi.org/10.1207/s15327809jls0604_1

Dunlosky, J., & Rawson, K. A. (2015). Do students use testing and feedback while learning? A focus on key concept definitions and learning to criterion. *Learning and Instruction*, *39*, 32–44. https://doi.org/10.1016/j.learninstruc.2015.05.003

Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology. *Psychological Science in the Public Interest*, *14*(1), 4–58. https://doi.org/10.1177/1529100612453266

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Fiorella, L., & Kuhlmann, S. (2020). Creating drawings enhances learning by teaching. *Journal of Educational Psychology*, *112*(4), 811–822. https://doi.org/10.1037/edu0000392

Fiorella, L., & Mayer, R. E. (2013). The relative benefits of learning by teaching and teaching expectancy. *Contemporary Educational Psychology*, *38*(4), 281–288. https://doi.org/10.1016/j.cedpsych.2013.06.001

Fiorella, L., & Mayer, R. E. (2014). Role of expectations and explanations in learning by teaching. *Contemporary Educational Psychology*, *39*(2), 75–85. https://doi.org/10.1016/j.cedpsych.2014.01.001

Fiorella, L., & Mayer, R. E. (2015). *Learning as a generative activity: Eight learning strategies that promote understanding*. Cambridge University Press. https://doi.org/10.1017/CBO9781107707085

Fiorella, L., & Mayer, R. E. (2016). Eight ways to promote generative learning. *Educational Psychology Review*, *28*(4), 717–741. https://doi.org/10.1007/s10648-015-9348-9

Garrison, D. R., Anderson, T., & Archer, W. (2000). Critical inquiry in a text-based environment: Computer conferencing in higher education. *The Internet and Higher Education*, *2*(2–3), 87–105. https://doi.org/10.1016/S1096-7516(00)00016-6

Gunawardena, C. N. (1995). Social presence theory and implications for interaction and collaborative learning in computer conferences. *International Journal of Educational Telecommunications*, *1*(2/3), 147–166.

Gunel, M., Hand, B., & McDermott, M. A. (2009). Writing for different audiences: Effects on high-school students' conceptual understanding of biology. *Learning and Instruction*, *19*(4), 354–367. https://doi.org/10.1016/j.learninstruc.2008.07.001

Guerrero, T. A., & Wiley, J. (2021). Expecting to teach affects learning during study of expository texts. *Journal of Educational Psychology*. https://doi.org/10.1037/edu0000657

Hockings, C., Thomas, L., Ottaway, J., & Jones, R. (2018). Independent learning—What we do when you're not there. *Teaching in Higher Education*, *23*(2), 145–161. https://doi.org/10.1080/13562517.2017.1332031

Hoogerheide, V., Deijkers, L., Loyens, S. M. M., Heijltjes, A., & van Gog, T. (2016). Gaining from explaining: Learning improves from explaining to fictitious others on video, not from writing to them. *Contemporary Educational Psychology*, *44–45*, 95–106. https://doi.org/10.1016/j.cedpsych.2016.02.005

Hoogerheide, V., Loyens, S. M. M., & van Gog, T. (2014). Effects of creating video-based modeling examples on learning and transfer. *Learning and Instruction*, *33*, 108–119. https://doi.org/10.1016/j.learninstruc.2014.04.005

Hoogerheide, V., Visee, J., Lachner, A., & van Gog, T. (2019). Generating an instructional video as homework activity is both effective and enjoyable. *Learning and Instruction*, *64*, 101226. https://doi.org/10.1016/j.learninstruc.2019.101226

Jacob, L., Lachner, A., & Scheiter, K. (2020). Learning by explaining orally or in written form? Text complexity matters. *Learning and Instruction*, *68*, 101344. https://doi.org/10.1016/j.learninstruc.2020.101344

Jahandarie, K. (1999). *Spoken and written discourse: A multi-disciplinary perspective*. Ablex Publishing Corporation.

Karpicke, J. D. (2009). Metacognitive control and strategy selection: Deciding to practice retrieval during learning. *Journal of Experimental Psychology: General*, *138*(4), 469–486. https://doi.org/10.1037/a0017341

Karpicke, J. D., & Blunt, J. R. (2011). Retrieval practice produces more learning than elaborative studying with concept mapping. *Science*, *331*(6018), 772–775. https://doi.org/10.1126/science.1199327

Karpicke, J. D., Butler, A. C., & Roediger, H. L. (2009). Metacognitive strategies in student learning: Do students practise retrieval when they study on their own? *Memory*, *17*(4), 471–478. https://doi.org/10.1080/09658210802647009

Kizilcec, R. F., Pérez-Sanagustín, M., & Maldonado, J. J. (2017). Self-regulated learning strategies predict learner behavior and goal attainment in massive open online courses. *Computers & Education*, *104*, 18–33. https://doi.org/10.1016/j.compedu.2016.10.001

Kobayashi, K. (2019). Learning by preparing-to-teach and teaching: A meta-analysis. *Japanese Psychological Research*, *61*(3), 192–203. https://doi.org/10.1111/jpr.12221

Koh, A. W. L., Lee, S. C., & Lim, S. W. H. (2018). The learning benefits of teaching: A retrieval practice hypothesis. *Applied Cognitive Psychology*, *32*(3), 401–410. https://doi.org/10.1002/acp.3410

Lachner, A., Backfisch, I., Hoogerheide, V., van Gog, T., & Renkl, A. (2020). Timing matters! Explaining between study phases enhances students' learning. *Journal of Educational Psychology*, *112*(4), 841–853. https://doi.org/10.1037/edu0000396

Lachner, A., Jacob, L., & Hoogerheide, V. (2021). Learning by writing explanations: Is explaining to a fictitious student more effective than self-explaining? *Learning and Instruction*, *74*, 101438. https://doi.org/10.1016/j.learninstruc.2020.101438

Lachner, A., Ly, K. T., & Nückles, M. (2018). Providing written or oral explanations? Differential effects of the modality of explaining on students' conceptual learning and transfer. *Journal of Experimental Education*, *86*(3), 344–361. https://doi.org/10.1080/00220973.2017.1363691

MacLeod, C. M., & Bodner, G. E. (2017). The production effect in memory. *Current Directions in Psychological Science*, *26*(4), 390–395. https://doi.org/10.1177/0963721417691356

McCallum, R. S., Sharp, S., Bell, S. M., & George, T. (2004). Silent versus oral reading comprehension and efficiency. *Psychology in the Schools*, *41*(2), 241–246. https://doi.org/10.1002/pits.10152

Miller, S. D., & Smith, D. E. (1985). Differences in literal and inferential comprehension after reading orally and silently. *Journal of Educational Psychology*, *77*(3), 341–348. https://doi.org/10.1037//0022-0663.77.3.341

Muis, K. R., Psaradellis, C., Chevrier, M., Di Leo, I., & Lajoie, S. P. (2016). Learning by preparing to teach: Fostering self-regulatory processes and achievement during complex mathematics problem solving. *Journal of Educational Psychology*, *108*(4), 474–492. https://doi.org/10.1037/edu0000071

Nestojko, J. F., Bui, D. C., Kornell, N., & Bjork, E. L. (2014). Expecting to teach enhances learning and organization of knowledge in free recall of text passages. *Memory & Cognition*, *42*(7), 1038–1048. https://doi.org/10.3758/s13421-014-0416-z

Nickerson, R. S. (1999). How we know—And sometimes misjudge—What others know: Imputing one's own knowledge to others. *Psychological Bulletin*, *125*(6), 737–759. https://doi.org/10.1037/0033-2909.125.6.737

Prinz, A., Golke, S., & Wittwer, J. (2020). How accurately can learners discriminate their comprehension of texts? A comprehensive meta-analysis on relative metacomprehension accuracy and influencing factors. *Educational Research Review*, *31*, 100358. https://doi.org/10.1016/j.edurev.2020.100358

Redeker, G. (1984). On differences between spoken and written language. *Discourse Processes*, *7*(1), 43–55. https://doi.org/10.1080/01638538409544580

Roediger, H. L., & Karpicke, J. D. (2006). Test-enhanced learning: Taking memory tests improves long-term retention. *Psychological Science*, *17*(3), 249–255. https://doi.org/10.1111/j.1467-9280.2006.01693.x

Roediger, H. L., & Pyc, M. A. (2012). Inexpensive techniques to improve education: Applying cognitive psychology to enhance educational practice. *Journal of Applied Research in Memory and Cognition*, *1*(4), 242–248. https://doi.org/10.1016/j.jarmac.2012.09.002

Roscoe, R. D., & Chi, M. T. H. (2007). Understanding tutor learning: Knowledge-building and knowledge-telling in peer tutors' explanations and questions. *Review of Educational Research*, *77*(4), 534–574. https://doi.org/10.3102/0034654307309920

Roscoe, R. D., & Chi, M. T. H. (2008). Tutor learning: The role of explaining and responding to questions. *Instructional Science*, *36*(4), 321–350. https://doi.org/10.1007/s11251-007-9034-5

Schober, M. F., & Brennan, S. E. (2003). Processes of interactive spoken discourse: The role of the partner. In A. C. Graesser, M. A. Gernsbacher, & S. R. Goldman (Eds.), *Handbook of discourse processes* (pp. 123–164). Lawrence Erlbaum Associates Publishers.

Short, J., Williams, E., & Christie, B. (1976). *The social psychology of telecommunications*. Wiley.

Sindoni, M. G. (2013). *Spoken and written discourse in online interactions*. Routledge. https://doi.org/10.4324/9780203587935

Tannen, D. (1983). Oral and literate strategies in spoken and written discourse. In R. W. Bailey & R. M. Fosheim (Eds.), *Literacy for life: The demand for reading and writing* (pp. 79–96). The Modern Language Association.

Tannen, D. (1985). Relative focus on involvement in oral and written discourse. In D. R. Olson, N. Torrance, & A. Hildyard (Eds.), *Literacy, language, and learning: The nature and consequences of reading and writing* (pp. 124–147). Cambridge University Press.

Tu, C. H., & McIsaac, M. (2002). The relationship of social presence and interaction in online classes. *The American Journal of Distance Education*, *16*(3), 131–150. https://doi.org/10.1207/s15389286ajde1603_2

Wittwer, J., Nückles, M., Landmann, N., & Renkl, A. (2010). Can tutors be supported in giving effective explanations? *Journal of Educational Psychology*, *102*(1), 74–89. https://doi.org/10.1037/a0016727

Yan, V. S., Bjork, E. L., & Bjork, R. A. (2016). On the difficulty of mending metacognitive illusions: A priori theories, fluency effects, and misattributions of the interleaving benefit. *Journal of Experimental Psychology: General*, *145*(7), 918–933. https://doi.org/10.1037/xge0000177

[Correction added on 21 October 2021, after first online publication: in the Reference list: 'Guerrerom' has been changed to 'Guerrero' in this version, in accordance with the authors' original submission.]

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