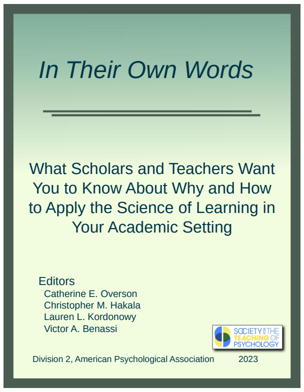

Learning by Teaching

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Overview

The best way to learn something new is to teach it to someone else. You have probably heard this proclamation before, and perhaps you have made it yourself. The idea that teaching others enhances one's own learning is far from new. In *Letters to Lucilius,* the first-century Stoic philosopher Seneca wrote, "while we teach, we learn." Over two thousand years later, many prevalent educational practices incorporate elements of learning by teaching (Duran & Topping, 2017), including peer tutoring programs (Leung, 2015; Roscoe & Chi, 2007), collaborative learning (Nokes-Malach et al., 2015), and small group discussions (van Blankenstein et al. 2011; Webb, 1982). In this chapter, I take a closer look at the evidence for learning by teaching, focusing on the benefits and boundary conditions associated with specific elements of teaching. Then I provide recommendations for how to implement teaching activities to enhance student understanding.

The term 'learning by teaching' suggests that explaining a concept to someone else will improve one's own understanding of the concept. However, I suspect this is not the full picture of what most people mean when they say that we learn best by teaching. Rather, they are often referring to how multiple elements of the teaching *process* benefit learning, such as by motivating students to process the learning material more deeply and to engage in meaningful interactions with others. In practice, learning by teaching often translates to, 'when I am *expected* to teach others, I need to make sure that I understand it myself,' or 'that my explanation is coherent,' or 'that I can respond to students' questions.' As I will describe in this chapter, there are three key elements of teaching—preparing, explaining, and interacting—each of which can provide unique cognitive, metacognitive, and motivational benefits.

Theoretical Framework

Learning by teaching can be classified as a *generative learning activity* because it encourages learners to actively make sense of what they are learning. According to generative learning theory (Fiorella & Mayer, 2015, 2016), making sense involves selecting key information from the learning material, organizing this information into a coherent structure in working memory, and integrating it with existing knowledge from long-term memory. Organizing and integrating are *generative* processes because learners must generate inferences to build appropriate relationships among the key ideas of the material. Generative processes are primarily driven by one's existing domain knowledge, strategic knowledge, and motivation to make sense of the learning material.

When learners are prompted with the prospect of teaching others, it may motivate them to engage in generative processing while preparing to teach, generating an explanation, and interacting with others. However, learners must have sufficient domain and strategic knowledge to make sense of the learning material, generate a coherent and comprehensive explanation, and effectively respond to questions. In other words, merely prompting learners to engage in a generative learning activity like teaching does not guarantee students will spontaneously engage in generative processing. Learners need instructional support to generate high-quality explanations for others that result in deep understanding (Roscoe & Chi, 2007). This chapter will identify learner and instructional characteristics that are most important for maximizing the benefits of learning by teaching.

Generative processing is closely connected to what Chi and Wylie (2014) refer to as the *constructive* mode of engagement in their ICAP (Interactive, Constructive, Active, Passive) framework, wherein teaching others may encourage students to monitor their understanding, generate inferences, and repair gaps or misconceptions in their existing knowledge (Chi & Boucher, this volume). The ICAP further classifies the *interactive* mode as the highest mode of engagement, in which learners actively engage in dialogue to ask questions or to clarify and elaborate on each other's ideas. Thus, when learning by teaching fosters productive interactions among students, it has the potential to enhance learning beyond other common learning activities that target lower levels of engagement, such as summarizing (*active* mode) or self-explaining (*constructive* mode).

Description and Discussion

Much of the prior research on learning by teaching involves evaluating peer tutoring programs, such as cross-age tutoring (in which more advanced students teach less advanced students) and reciprocal teaching (in which students take turns teaching each other) compared to more conventional forms of instruction (Duran & Topping, 2017; Leung, 2015; Roscoe & Chi, 2007). Although valuable, these studies are limited in their ability to isolate the specific 'active ingredients' of teaching that are responsible for learning. According to Bargh and Schul (1980), learning by teaching consists of three distinct stages, which may uniquely contribute to learning: preparing to teach, generating an explanation for others, and interacting with others. In the following sections, I focus on research that isolates the unique and additive benefits at each stage of the teaching process.

Benefits and Boundaries of Preparing to Teach

Learners typically approach learning tasks with the goal of supporting their own learning, such as when studying for an upcoming test. Do students benefit more from studying with the expectation to teach others? One hypothesis is that the social responsibility of teaching others may motivate learners to study in a more effortful and effective way. An early study by Benware and Deci (1984) found that students who expected to teach the contents of an article on brain functioning were more intrinsically motivated to learn and achieved better conceptual understanding of the material than students who expected to take a test. They concluded that preparing to teach promotes a more active 'motivational set' than the way in which students typically study. In other words, the prospect of teaching others can shift students' mindset toward actively making sense of the learning material.

More recent research has helped to uncover the specific cognitive and metacognitive mechanisms underlying preparing to teach. In a study by Nestojko and colleagues (2014), college students studied text passages with the expectation of either teaching or taking a test. Then both groups of students completed a free recall test and answered targeted questions about the content of the texts. Students who expected to teach generated more organized and complete recall of the passages and performed better on questions targeting the main ideas of the passage than students who expected a test. Similar findings were reported in a study by Muis and colleagues (2016) involving elementary students in math. Students who prepared to teach developed more organized representations of math problems, engaged in more metacognitive processing strategies, and exhibited higher problem-solving achievement than students who prepared normally for a test. Taken together, these studies suggest preparing to teach may help students better organize the learning material around key ideas, resulting in better learning outcomes.

Despite the benefits of preparing to teach, research also suggests potential boundary conditions. Some studies report either no benefits or inconsistent effects of learning by expecting to teach compared to expecting a test (e.g., Ehly et al., 1987; Hoogerheide et al., 2014; Renkl, 1995). For example, Renkl (1995) found students did not benefit from preparing to teach probability worked examples, likely because students reported experiencing high levels of anxiety at the prospect of teaching. Thus, although teaching can be motivating, under some conditions it can be stressful and potentially interfere with learning.

Another explanation for the mixed findings is that the expectation of teaching encourages, but does not guarantee, that students will apply appropriate strategies for making sense of the material. In other words, higher levels of motivation or effort do not necessarily support learning if they do not lead to productive generative processing. A study by Fukaya (2013) suggests students have different metacognitive knowledge about what constitutes a quality explanation. Some students are more oriented toward preparing elaborative explanations that connect the learning material with their existing knowledge, whereas others take a summarization approach that does not incorporate their prior knowledge. In terms of the ICAP framework, preparing to teach may reach the 'constructive' mode of engagement for some, but for others it may only reach the 'active' mode. As expected, Fukaya (2013) only found benefits of preparing to teach among students oriented toward preparing elaborative explanations.

There is also some inconsistency in the literature about whether preparing to teach supports long-term learning. In a series of studies by Fiorella and Mayer (2013, 2014), undergraduate students who prepared to teach a lesson on the Doppler effect performed better on an immediate comprehension test, but not a delayed comprehension test, compared to students who prepared normally for a test. In contrast, a recent study by Guerrero and Wiley (2021) found a teaching expectancy effect for immediate *and* delayed comprehension. Further research is needed to understand the conditions under which preparing to teach (without actually teaching) leads to long-term learning. As discussed later, long-term outcomes may be strongest when students have the opportunity to prepare *and generate* an explanation for others.

Overall, prompting learners to prepare to teach offers an easy-to-implement technique that can motivate learners to engage in generative processing. A recent meta-analysis by Kobayashi (2019a) found a small-to-medium average effect size (d = .30 to .40) across 28 studies favoring preparing to teach over preparing for a test. The evidence reviewed in this section suggests this effect may be moderated by the extent to which learners experience excessive anxiety at the prospect of teaching, the beliefs learners have about their ability to generate quality explanations, and the quality of strategies learners use when preparing to teach. Thus, instructors may consider using a relatively low-stakes teaching expectancy prompt and instructing students on the elements of quality explanations and strategies for preparing explanations for others.

Benefits and Boundaries of Explaining to Others

The prospect of teaching is a simple way to leverage students' expectations to support learning. Are there added benefits of actually teaching the material to someone else? An early study by Annis (1983) found that students better understood the contents of a history text when they prepared to teach and then actually taught a peer compared to when they only prepared to teach. This study was somewhat limited, however, because students who taught also *interacted* with their peers, such as by responding to questions. Thus, the study cannot isolate the effects solely due to explaining to others.

To overcome this limitation, more recent work has isolated the effects of asking students to generate non-interactive explanations for fictitious peers, such as by recording a video lecture or composing a written explanation. In a series of experiments by Fiorella and Mayer (2013, 2014), college students learned about the Doppler effect with the expectation of teaching or taking a test. Of those expecting to teach, some students actually taught by creating a video lecture intended to teach a fictitious student who does not know about the learning material. On immediate comprehension tests, students who prepared to teach performed similarly, regardless of whether they actually taught on video. However, students who actually taught performed best on a delayed comprehension test. There was also evidence that the added benefit of teaching was strongest on a delayed test when students prepared to teach (rather than prepared for a test). Hoogerheide and colleagues (2014) reported a similar pattern of results in which actually teaching on video led to better understanding than only preparing to teach.

Why does generating an explanation for others enhance learning? One explanation is that it involves retrieving the learning material from memory, which strengthens the memory of that information and makes it more accessible over time. To test this idea, Koh and colleagues (2018), using the same materials from Fiorella and Mayer (2013, 2014), asked students to teach the Doppler effect lesson on video either from memory or with teaching notes available to them. Other students did not teach and were asked to only recall the information from memory. Results indicated that students asked to retrieve the information from memory (either via teaching or via a recall test) outperformed students on a delayed comprehension test who taught while having access to teaching notes. This finding suggests learning by teaching is most effective when used as a retrieval activity. It is important to note, however, that the benefits of explaining to others are not solely explained by retrieval processes. Other studies have found that explaining as a retrieval activity is more effective than merely taking a free-recall test (Jacob et al., 2020; Lachner et al., 2021), likely because explaining better primes students to organize and integrate the material with their existing knowledge (Fiorella & Mayer, 2016). Furthermore, teaching involves adapting an explanation for one's audience, which may also play a unique and important role in supporting learning (Rittle-Johnson et al., 2008).

Another consideration is whether students should generate written or oral explanations when teaching others. Hoogerheide and colleagues (2016) found that orally teaching syllogistic reasoning problems on video was more effective than restudying the learning material, but teaching via written explanations was not more effective than restudying. There was not a significant difference in performance between the oral and written explanation groups, so this study could not draw strong conclusions about the role of explanation modality. Lachner and colleagues (2018) took a closer look at differences in the quality of students' written and oral explanations and their relationship with different learning outcomes. Written explanations tended to be more organized and contributed to better conceptual understanding; in contrast, oral explanations tended to be more elaborative and contributed to better transfer test performance. Interestingly, the studies by Hoogerheide and colleagues (2016) and Lachner and colleagues (2018) both found that students' oral explanations contained more audience-directed speech, in which students used first- or second-person pronouns like 'I' and 'you'. This finding suggests the benefits of orally explaining may be in part due to greater feelings of *social presence*, or the sense that one is in communication with an audience.

A recent study by Jacob and colleagues (2020) suggests the benefits of orally explaining may also depend on the nature of the learning materials: orally explaining was more effective when students learned from texts higher in complexity but not lower in complexity. Further, the benefits of orally explaining complex texts were mediated by higher levels of audience-directed speech in students' explanations and more comprehensive explanations. Overall, oral explanations appear to create higher levels of social presence and make it easier for students to elaborate on the learning material, facilitating sense making of more complex learning materials.

The research described above suggests that explaining to others is most effective when students prepare with the expectation of teaching, explain as a retrieval activity, and generate oral explanations. However, without additional support, many students may still struggle to generate high-quality explanations that support deep understanding. According to Roscoe (Roscoe, 2014; Roscoe & Chi, 2007, 2008), students exhibit a 'knowledge-telling bias' when prompted to explain to others, in which they simply restate or summarize the learning material while making minimal inferences. The goal is for students to engage in 'knowledge-building' – similar to generative or constructive processing – in which they actively monitor their understanding and use their existing knowledge to elaborate on the learning material.

One simple way to foster knowledge building in learner-generated explanations is to incorporate the use of instructional visualizations (e.g., Ainsworth & Loizou, 2003; Butcher, 2006; Cromley et al., 2010). In a recent study, Fiorella and Kuhlmann (2020) explored whether creating drawings helped learners generate higher-quality explanations during learning by teaching. College students studied a lesson on the human respiratory system and then recorded a video lecture to a fictitious student. Students either orally explained (explain-only), created drawings (draw-only), or orally explained while simultaneously creating drawings (explain-and-draw). A control group of students restudied the learning material without teaching. Results indicated all teaching conditions significantly outperformed the control group on a series of learning outcome measures (including a transfer test) administered one week later. Furthermore, the explain-and-draw group significantly outperformed the explain-only and draw-only groups, which did not differ from each other. Analyses of students' explanations indicated that students who created drawings while explaining generated more elaborative explanations (an indicator of knowledge building) than students who only explained. This study suggests that drawing facilitates explaining, which leads to better understanding. An open question is whether learner-generated drawings and instructor-provided visuals might differentially impact learning by teaching (Fiorella, 2021). Related research suggests learners may benefit from a combination of generated and provided visuals (Zhang & Fiorella, 2019, 2021).

Overall, generating explanations for others enhances learning beyond only preparing to teach and is generally more effective than restudying or engaging in retrieval tasks like free recall tests. The review by Kobayashi (2019a) reports a medium average effect size (d = .5 to .6) across 28 studies when students both prepare to teach and actually teach others. For explaining to be most effective, learners need guidance to facilitate knowledge building, such as the use of provided visualizations (e.g., Ainsworth & Loizou, 2003), focused prompts to explain or draw key elements of the learning material (e.g., Berthold, Eysink, & Renkl, 2009; Fiorella & Mayer, 2017), and explicit training and practice on how to generate quality explanations (e.g., McNamara, 2004).

Benefits and Boundaries of Interacting with Others

According to the ICAP framework (Chi & Wylie, 2014), the highest mode of cognitive engagement is the *interactive* mode, in which learners work together to co-construct knowledge of the learning material. Thus, learning by teaching should have the highest potential to support deep learning when it involves preparing to teach, generating an explanation, and engaging in quality *interactions* with one's peers, such as asking and responding to questions.

In a recent review, Kobayashi (2019b) distinguished two approaches for examining the effects of interactivity in learning by teaching. The first approach is to compare learning by teaching a live audience (higher interactivity) to learning by self-explaining (lower interactivity). Thus, this approach allows researchers to isolate the effects of explaining to an audience. Coleman and colleagues (1997) found that students learned better from preparing for and actually explaining the material to others compared to preparing for and explaining the material to themselves. Similarly, Rittle-Johnson and colleagues (2008) found young children benefited more from explaining math problems to their mothers than generating self-explanations. In contrast, some studies have found either no differences or an advantage of self-explaining over teaching (Bargh & Schul, 1980; Pi et al., 2021; Roscoe & Chi, 2008). Yet in these studies, participants were not informed prior to the study period that they would later explain the material to others. Thus, the social interactivity associated with both preparing and actually explaining to a live audience may offer unique benefits beyond self-explaining, which itself is an effective learning strategy (Bisra et al., 2018).

Recent studies suggest another way in which the benefits of explaining to others may depend on interactivity. Lachner and colleagues (2021) found that students learned better from writing explanations for oneself than for teaching others. As discussed above, written explanations may not be the most suitable implementation of learning by teaching because they do not incorporate high degrees of interactivity or feelings of social presence. A follow-up study by Jacob and colleagues (2021) found that trying to increase the level of social presence in written explanations (by typing explanations into a chat box) was not sufficient to boost learning. Thus, *explaining orally to an audience* may be an important component of interactivity, although further research is needed to test other ways in which written explanations might create higher levels of social presence.

The second approach for studying the effects of interactivity is to compare teaching with or without the opportunity to subsequently engage in dialogue with others, such as asking and responding to questions. Thus, this approach allows researchers to isolate the effects of interactive dialogue during teaching. Surprisingly few studies have made this direct comparison (Kobayashi, 2019b). Roscoe and Chi (2008) found that college students learned better from interactive teaching, which involved answering questions from a tutee, than from non-interactive teaching, which involved recording a video lecture. Similarly, a recent study by Kobayashi (2021) found that teaching with a subsequent question-and-answer period benefited learning beyond only teaching without interacting. Thus, there is some empirical evidence that opportunities for student interaction can provide additive benefits to learning by teaching.

Why might interacting with others boost learning? One explanation is that asking and responding to questions encourages tutors to engage in knowledge building, in which they reflect on their understanding and attempt to clarify or revise their understanding of the learning material. In the study by Roscoe and Chi (2008), tutors engaged in more knowledge building when tutees asked questions that required generating inferences. Similarly, Roscoe (2014) found that the number of conceptual questions posed by tutees was predictive of knowledge building among tutors which, in turn, supported deeper understanding. However, analyses of tutor-tutee interactions reveal that tutees rarely ask deep, conceptual questions that provoke knowledge building in tutors. A recent study by Wang and colleagues (2021) further indicates that merely having the opportunity to interact with a peer does not guarantee that the interaction will lead to knowledge building. In that study, imagined teaching, in which students only imagined the process of teaching, was actually more effective than interactive teaching.

Taken together, opportunities to ask and respond to questions can benefit learning, but students need support to engage in effective questioning activities during learning. One remedy may be to take advantage of the preparation phase of teaching, as preparing to teach may help students better ask, anticipate, and respond to questions from peers. Related research suggests that collaborative learning is most effective when students have the opportunity to first prepare individually (Mende et al., 2021).

Other potential solutions include providing explicit training in explaining and questioning strategies or providing prompts or scaffolds to structure peer interactions (e.g., Fuchs et al., 1994; King, 1994; King et al., 1998), so that students do not have to fully generate explanations and questions themselves. In short, students need support to pose provocative questions that lead to reflective, elaborative, and accurate explanations.

Recommendations

The available research evidence generally supports our intuitions – teaching others can indeed be a highly effective way to learn. However, simply prompting students to teach others will not necessarily result in better understanding. The research reviewed in this chapter provides a set of basic guidelines for when and how to implement learning by teaching activities most effectively.

Learner Characteristics

Instructors should first consider individual differences in learners' levels of background domain knowledge, strategic knowledge, and motivation. First, learners need sufficient *domain knowledge* to generate appropriate inferences from the learning material (Roscoe, 2014). In other words, the learning materials need to be 'knowledge-appropriate.' Learners without the requisite prior knowledge may need pre-training before engaging in learning by teaching. Second, learners need sufficient *strategic knowledge* of what constitutes quality explanations and interactions with others. Although some students may already be oriented toward generating elaborative explanations, many learners approach the tasks of explaining and interacting with others passively and rely on knowledge-telling. Instructors can help students develop strategic knowledge by using examples to explicitly model effective explaining and questioning in their particular disciplines. Third, learners need sufficient *motivation* to engage in learning by teaching. Although the prospect of teaching others can be motivating, in some situations it may be stressful. Thus, learners may need the opportunity to prepare and practice in a supportive environment to experience the benefits of learning by teaching. Instructors may also want to use learning by teaching primarily as low-stakes learning activities and formative assessments.

Learning Materials

Instructors should also consider the nature of the learning materials when implementing learning by teaching. Learning by teaching is most suitable for conceptual learning materials, such as understanding how a system works or underlying problem-solving principles. It may not be as effective for remembering relatively isolated factual information, such as foreign language vocabulary words. Prior research has mostly involved explaining complex concepts in math and science, such as how the Doppler effect works, how electric circuits work, how the human retina works, or how to apply principles of probability (e.g., Fiorella & Mayer, 2013; Hoogerheide et al., 2019a; Roscoe, 2014). The format of these learning materials has included text passages, visualizations, and worked examples. Although prior research has focused primarily on mathematics and science concepts, instructors could likely adapt learning by teaching activities to fit conceptual materials across other disciplines, such as the humanities (e.g., Pi et al., 2021).

Applications of Learning by Teaching

There are many potential applications of learning by teaching that extend beyond conventional classroom activities. For example, students may be asked to create brief instructional videos as a homework assignment, rather than typical homework assignments, such as reading or answering practice questions. Hoogerheide and colleagues (2019b) found that recording an instructional video as homework was more effective and enjoyable for students than conventional homework activities.

Similarly, students can learn by teaching within remote classrooms by either pre-recording videos or engaging in live video interactions with other students. Virtual tools, such as screen sharing or the ability to construct visualizations, may also help facilitate knowledge building. Other technology-based applications include the use of interactive computer-based avatars (or 'pedagogical agents,' e.g., Biswas et al., 2005), virtual reality (Klingenberg et al., 2020), and educational games (Fiorella et al., 2019). Research suggests that students can benefit from teaching and interacting with intelligent virtual agents or by explaining content presented in a virtual classroom, as long as these environments do not impose excessive extraneous cognitive load (e.g., Fiorella et al., 2019; Ashman & Sweller, this volume). Overall, technology-based tools offer promising ways to provide adaptive guidance to support quality student explanations and deeper understanding.

Implementation

Instructors may choose to incorporate one or more of the following key elements of learning by teaching into course activities: preparing, explaining, and interacting. First, preparing to teach offers a simple way to shift students' expectations and orient them toward making sense of the learning material. For example, students could be instructed to read and take notes on a textbook chapter as if they were preparing to teach another student who has not read the chapter. Second, actually generating an explanation can encourage students to monitor their understanding and generate inferences. Explaining may be most effective when students prepare with the expectation of teaching, explain orally to a live audience, and explain as a retrieval activity. For example, at the beginning of a lesson, instructors can inform students that they will later teach the key concepts to a peer. After the lesson, instructors can provide students time to prepare their explanations before actually explaining the concepts to a peer, without access to their notes or the learning material. Third, providing students with the opportunity to interact with each other can further encourage students to monitor their understanding, clarify, and elaborate on the learning material. Instructors can encourage students to ask and respond to questions that require inference generation or apply knowledge to a new situation. Instructors may also incorporate reciprocal teaching (e.g., Palincsar & Brown, 1984), in which students take turns explaining concepts to each other and asking for clarification or elaboration questions.

At each stage of the teaching process, students will likely need instructional support. The literature on generative learning strategies suggests three primary modes of guidance: modeling, scaffolding, and feedback (Fiorella & Zhang, 2018). At the *preparing* stage, students need to know what constitutes a quality explanation and how to translate the provided explanations into a coherent explanation for others. Instructors can model the process of preparing to teach, provide scaffolds such as outlines or visualizations to facilitate organization, and provide feedback on the quality of students' lesson plans. At the *explaining* phase, students need support to generate explanations that involve knowledge building. Instructors can use examples to model the (meta)cognitive processes of monitoring and inference generation, provide students with focused prompts to explain key relationships or to create visualizations, or provide feedback on the coherence, accuracy, and completeness of students' explanations. Finally, at the *interacting* phase, students need support on how to generate conceptual questions that encourage knowledge building. Instructors can provide examples of inference questions to pose, provide partial scripts to guide students toward quality interactions (e.g., 'Can you provide a concrete example of X?' 'How would X apply in Y situation?') or provide feedback on how to shift questions targeting *knowledge telling* more toward *knowledge building*. Overall, when students receive adequate support at each stage of the process, learning by teaching can serve as a highly effective strategy for supporting student understanding.

Author Note

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